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Thesis for the degree of Doctor of Technology to be presented with due permission for public examination and criticism in Auditorium RG202, at Tampere University of Technology, on the 16th of April 2004, at 12 o'clock noon.

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ABSTRACT

The European Committee for Standardization published in 1998 the first two parts of Standard EN 1317 under the general title: Road restraint system. The published parts specified the requirements and methods for full-scale impact tests on safety barriers. Within the same year the European standard was given the status of a Finnish national standard.

If public funding is involved, the safety barrier to be used in new building must conform to the requirements of the European standard. The safety barrier generally used in Finland on bridges, the standard vehicle parapet of the Finnish Road Administration, did not conform to the standard according to the arranged full-scale impact tests. Thus began the development process described in this thesis.

The unit of analysis of this thesis is the development method of new Finnish standard vehicle parapets. The aim of the study was to prove that the vehicle parapets conform to the impact test acceptance criteria of Standard EN 1317, can be developed at a reasonable cost by using an analysis method, which was a combination of calculation analyses, full-scale impact tests and experience received from the process. The goal was to improve road safety by developing impact-safer vehicle parapets.

The new Finnish standard safety barriers to be used on bridges, Finnra H1 and H2 vehicle parapets, were successfully developed with the chosen method so that they conform adequately to Standard EN 1317. Suitable further development of the used analysis method was thought to be the implementation of more reality-accurate finite element systems. It was also defined as one of the main development area of the standard.

The costs of increasing the safety of vehicle parapets in Finland will be about equal to what is saved in accident costs. The number of injuries will decrease and the high risk of severe consequences in public transport vehicle accidents will fall without any notable additional cost.

The "Vehicle parapets" publication of the Finnish Road Administration is going to be released later as a result of the development process. It will consist of a design manual and the quality requirements for the vehicle parapets to be used in Finland as well as the drawings of the new Finnish standard vehicle parapets.

Keywords: accident cost, computer simulation, containment level, EN 1317, impact severity, impact test, restraint system, safety barrier, vehicle parapet

FOREWORD

The development work constituting the basis of this thesis was carried out for the Finnish Road Administration (Finnra) at A-Insinöörit Oy during the period 1999-2002. This thesis, written at the Laboratory of Structural Engineering at Tampere University of Technology (TUT), goes deeper into the subject.

The thesis deals with the development of new Finnish standard vehicle parapets. The development project was the consequence of the full-scale impact tests arranged in 1998 and 1999, where the tested standard vehicle parapet of Finnra did not fulfil the requirements of Standard EN 1317 announced at the time.

I would like to thank my employer, A-Insinöörit Oy, for creating a challenging environment, where I have been able to develop my engineering skills, and Finnra for enabling me to study this subject. Finnra, the Laboratory of Highway Engineering at Helsinki University of Technology (HUT), TTP-Yhtiöt Oy, FORCE Technology Sweden AB and the Swedish National Road Administration deserve thanks for their good co-operation.

Professor Ralf Lindberg, Head of the Department of Civil Engineering and the Laboratory of Structural Engineering at TUT, has been my mentor since my basic civil engineering studies. He played a crucial role in my starting to write this thesis and in maintaining my faith in the subject through the project, for which I am deeply grateful.

The assessors of my thesis were Dr.-Ing. Ríkharður Kristjánsson, Línuhönnun Ltd., Iceland and D.Tech. Jarkko Valtonen, the Laboratory of Highway Engineering at HUT, who deserve thanks for their help.

I am deeply indebted to the Industrial Research Fund at Tampere University of Technology, A-Insinöörit Oy, the Laboratory of Structural Engineering at TUT, the Association of Finnish Civil Engineers RIL Foundation, Rautaruukki Steel Structure Division and the Finnish Society of Consultants SNIL Scholarship Fund for the grants they gave me to write my thesis.

Finally, I express my gratitude to my wife Marika for providing understanding, love and encouragement during this project.

In loving memory of my grandmother to whom this meant so much.

Tampere, January 2004

Vesa Järvinen

TABLE OF CONTENTS

TERMINOLOGY

Crash cushion

A road vehicle energy absorbing device installed in front of a rigid object to reduce the severity of impact.

Dynamic analysis

Analysis of structure where the loadings may not be considered static and/or general inertia and damping (the property that causes dissipation of energy in a system) effects are significant.

Handrail

A rigid rail attached to a safety barrier to assist and guide pedestrians.

Infill

A material that is fixed to posts and/or rails of a safety barrier in order to reduce the size of openings (voids).

Linear analysis

Analysis of structure where the load-deflection response is linear.

Lower rail

A horizontal member of a safety barrier under the rail, which prevents severe collision of a vehicle against the posts.

Middle rail

A horizontal member of a safety barrier, which reduces the size of the openings (voids).

Nonlinear analysis

Analysis of structure where the load-deflection response is not linear.

Pedestrian parapet

A pedestrian or other user (incl. equestrians, cyclists and cattle) restraint system along the edge of a footway or footpath intended to restrain pedestrians and other users from stepping onto or crossing a road or other area likely to be hazardous.

Pedestrian restraint system

A system installed on the road to provide guidance for pedestrians.

Permanent safety barrier

A safety barrier installed permanently on the road.

Post

A vertical member of a safety barrier, which withstands both horizontal and vertical forces and transmits these forces to the supporting structure.

Rail

A horizontal member of a safety barrier, which transmits horizontal and vertical forces to the posts.

Road restraint system

General name for a vehicle restraint system and pedestrian restraint system used on a road.

Safety barrier

A road vehicle restraint system installed alongside, or on the central reserve, of a road.

Static analysis

Analysis of structure where the loadings are considered static and general inertia and damping effects are insignificant.

Temporary safety barrier

A safety barrier which is readily removable, and used at road works, emergencies or similar situations.

Terminal

An end treatment of a safety barrier.

Transition

Connection of two safety barriers of different design and/or performance.

Vehicle parapet

A safety barrier installed on the edge of a bridge or on a retaining wall or similar structure where there is a vertical drop and which may include additional protection and restraint for pedestrians and other road users.

Vehicle restraint system

A system installed on the road to provide a level of containment for an errant vehicle.

NOTATION

Symbols

A	higher impact severity level (lower value of ASI required), also distance for exit box criterion (perpendicular to the restraint system)
B	lower impact severity level (higher value of ASI allowed), also distance for exit box criterion (parallel to the restraint system)
D	dynamic deflection (maximum lateral dynamic displacement of the side facing the traffic of the restraint system during the vehicle impact)
D_x	distance of the notional impact surface inside the vehicle from the original head position along the vehicle body axis x (flail distance)
D_y	distance of the notional impact surface inside the vehicle from the original head position along the vehicle body axis y (flail distance)
I	the moment of inertia
M_u	elastic moment capacity (ultimate value before yielding)
T	kinetic energy
W	working width (the distance between the side facing the traffic before the vehicle impact on the restraint system and the maximum dynamic lateral position of any major part of the system)
$\bar{a}x$	component of acceleration along the vehicle body axis x
$\hat{a}x$	limit value for the component of acceleration along the vehicle body axis x
$\bar{a}y$	component of acceleration along the vehicle body axis y
$\hat{a}y$	limit value for the component of acceleration along the vehicle body axis y
$\bar{a}z$	component of acceleration along the vehicle body axis z
$\hat{a}z$	limit value for the component of acceleration along the vehicle body axis z
g	acceleration of free fall due to gravity
m	total vehicle mass
v	impact speed of the vehicle
α	impact angle of the vehicle

Abbreviations

ASI	Acceleration Severity Index
BASt	Bundesanstalt für Straßenwesen
CEN	European Committee for Standardization
CPU	Central Processing Unit
ECV	Electronically Controlled Vehicle
EN	European Standard
ENV	European Prestandard
EU	European Union (enlarges from 15 to 25 Member States on 1 May 2004)
EUR	Euro (official currency unit of the of the member countries of the EU who have adopted European Monetary Union)
FE	Finite Element
FEM	Finite Element Method
Finnra	Finnish Road Administration (previously e.g. FinnRA: Finnish National Road Administration)
HGV	Heavy Goods Vehicle
HUT	Helsinki University of Technology
NCAC	National Crash Analysis Center
PHD	Post-impact Head Deceleration
prEN	Draft European Standard
SFS	Finnish Standards Association
SNRA	Swedish National Road Administration
THIV	Theoretical Head Impact Velocity
TUT	Tampere University of Technology
VTI	Swedish National Road and Transport Research Institute

1 INTRODUCTION

1.1 Definition of vehicle parapet

A vehicle parapet is a safety barrier installed on the edge of a bridge or on a retaining wall or similar structure where there is a vertical drop and which may include additional protection and restraint for pedestrians and other road users (SFS-EN 1317-1 1998). A vehicle parapet with safe impact performance will adequately absorb vehicular impact energy, prevents the overturning of a vehicle, and guides a vehicle so that its rebound angle is sufficiently small.

1.2 Influence of the European standard

1.2.1 Implementation of the standard

The European Committee for Standardization (CEN) announced in 1998 the first two parts of Standard EN 1317 under the general title: Road restraint system. The published parts specified the requirements and methods for full-scale impact tests on safety barriers. Within the same year the European standard was given the status of a Finnish national standard. No Finnish standards concerning the testing of the safety barriers existed before.

The procurement directive of the European Union (EU), the Finnish law on public procurement and related decrees provide that if public funding is involved, a safety barrier to be used in new building must conform to the requirements of the European standard. A vehicle parapet must be approved according to Standard EN 1317 in Finland or some other country, and it has to be suitable for Finnish conditions (Finnish National Road Administration 1995, Finnish Road Administration 2002). The Finnish Road Administration (Finnra) is the approving authority in Finland.

1.2.2 Need for development of vehicle parapets

In 1998 and 1999 Finnra arranged full-scale impact tests consistent with Standard EN 1317 for its standard vehicle parapet. The aim was to prove that the vehicle parapet generally used in Finland at the time satisfied the requirements of the standard. The impact performance revealed by the tests was not satisfactory and led to the development process described in this thesis to produce national vehicle parapets alternatives that conform to the standard.

1.3 Development process

1.3.1 Overview

The unit of analysis of this thesis is the development method for new Finnish standard vehicle parapets. The costs of increasing the safety of Finnish vehicle parapets have also been estimated to get an idea of the cost effect. The arrangements of the full-scale impact tests are not the research subject here. The groundwork for the development has been done as consultancy work for Finnra by the author of this doctoral thesis at A-Insinöörit Oy. This thesis goes deeper into the subject, for instance, in the area of accident cost-effect analysis and future development aspects. It has been written as a separate piece of academic work in parallel with the final stage of the consultancy.

1.3.2 Process description

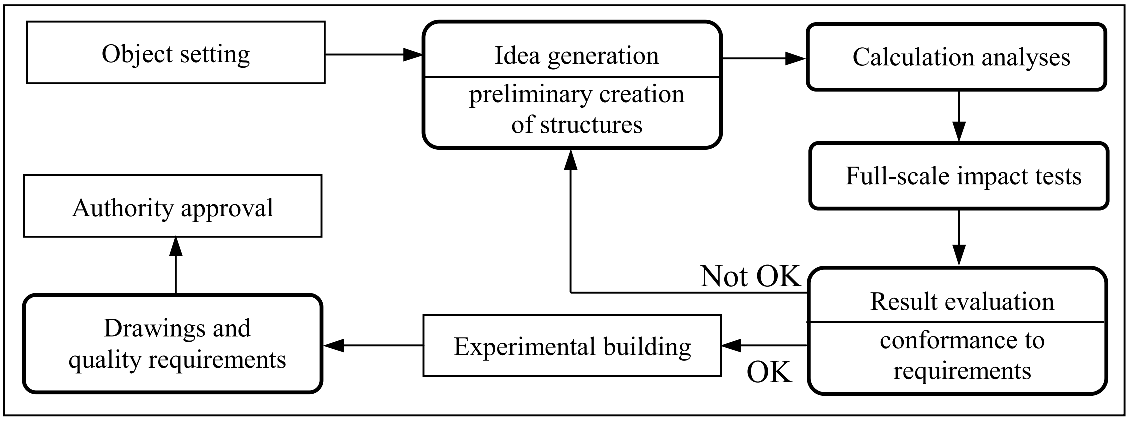

Figure 1.1 Development of new Finnish standard vehicle parapets.

A general description of the development process is presented in Figure 1.1. The process started at the end of 1999 with a study of vehicle parapets conforming to Standard EN 1317. The objectives for the development of new Finnish standard vehicle parapet types were created by comparing these parapets. The analysing and impact testing of the developed structures was done in 2000-2003. The development process was controlled by the group, which consisted of authorities, consultants and, in different stages of the process, also representatives of the impact testing laboratory and manufacturers.

During the process experimental building of developed vehicle parapets was used along with actual bridge projects to finish the details of the parapets. At the end of the project the publication “Vehicle parapets” (Finnish Road Administration 2002) was prepared; it will be released later. It consists of a design manual and the quality requirements for vehicle parapets to be used in Finland as well as the drawings of new Finnish standard vehicle parapets.

1.4 Related development projects

Finnra has developed and impact-tested also safety barriers installed on roads according to Standard EN 1317. In the next phase, the transitions, the connections between safety barriers on roads and bridges, shall be put under research (Fig. 1.2). The parts of Standard EN 1317 concerning them and terminals, the end treatments of the safety barriers, have been released as a European prestandard (ENV). There has already been development work on transitions and terminals, but the certification of the structures with the impact tests consistent with the European standard are still to be done.

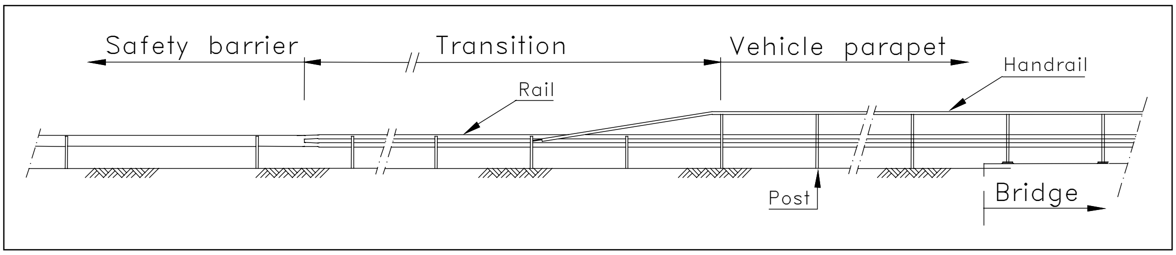

Figure 1.2 General drawing of a vehicle restraint system installed alongside a road and bridge. In the illustrated case the transition has the same rail and post spacing as the vehicle parapet. The safety barrier on a road has a less rigid rail and less dense post spacing (Finnish Road Administration 2002).

2 BACKGROUND OF THE STUDY

2.1 Road safety

About 40,000 people die annually in road traffic accidents in the 15 countries of the European Union. The annual cost of road accidents is of the order of 160 billion EUR including the directly measurable cost and the physical and psychological damage suffered by the victims and their families. The sum is equal to 2 per cent of the EU's gross national product. The EU has set itself the goal of reducing the number of people killed in road accidents by half between 2000 and 2010 (European Commission 2001).

In Finland about 400 people die in road traffic accidents each year — about one fourth in run-of-the-road accidents like collisions against safety barriers (Kelkka 2002). Finnish society's endeavour to improve road safety is apparent in the Council of State decisions in principle of 1997 concerning road safety improvement. The objective was to continue reducing the most serious injuries and the annual number of fatalities, so that in 2005 they would be less than 250. Later, the schedule was considered too tight, and in 2001 the target was moved to the year 2010. In the Road Safety 2005 strategy (Finnish National Road Administration 1999b) Finnra has committed itself to large-scale development of activities and measures for continued improvement of road safety.

The number of deaths in fatal accidents against parapets on bridges in Finland in the last decade are presented in Figure 2.1. The statistics are based on reports: Kallberg et al. (1993), Salmela et al. (1995) and Kelkka (2002). About half of the fatal accidents involved collision against a terminal pier. It is a block, normally of concrete, between the safety barrier on the road and on the bridge, which often cuts the continuity of the rail. The accident type was even more common earlier, but due to the modification of the existing terminal piers the number of accidents has reduced. Nowadays, terminal piers cannot be built on bridges. The different accident types are:

A. Direct collision against a parapet on a bridge
B. Collision against a parapet on a bridge after another collision (e.g. against safety barrier on the road or terminal pier)
C. Collision against the terminal pier of the parapet on a bridge

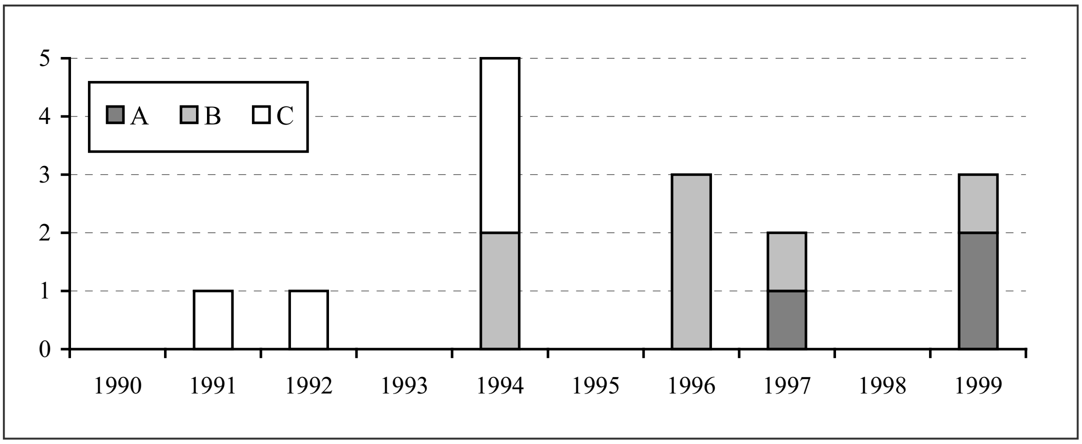

Figure 2.1 Number of deaths in Finland in the 1990's in fatal accidents against parapets on bridges. Accident types A…C shown in the bar chart are explained above.

The amount of deaths in fatal accidents alone does not give a comprehensive view of the casualties in traffic accidents. The total amount of personal injuries, including deaths, in collisions against the side of a safety barrier is about 19.5 times higher than the number of deaths. In the case of collisions against terminals the number of personal injuries is about 8.8 times higher than the amount of deaths (Finnish National Road Administration 1999a). The accident cost per injury in a collision against the side of a safety barrier is about 134,000 EUR and against the end treatment of the safety barrier about 280,000 EUR (Finnish National Road Administration 1999c).

An average of 1.5 people died annually in the 1990's in collisions against parapets on bridges. Because one third of these were caused by collisions against terminals (the amount is about the same with or without the terminal pier as the accident factor), the estimated total amount of injured people per year was 24 while the total cost was about 3.85 million EUR. An important safety aspect of a safety barrier on a bridge is the higher risk of severe consequences than with a safety barrier on the road, if, for instance, a public transport vehicle full of passengers collides against the barrier. As a matter of fact one trigger for vehicle parapet development in the 1960's presented in the next chapter was an accident where a bus drove through a vehicle parapet into the Imatrankoski Rapids.

2.2 Finnish impact tests before the European standard

2.2.1 Introduction

In the summer of 1964 the Finnish Roads and Waterways Administration (the predecessor of Finnra) organised impact tests in Finland at the Hyvinkää airport because of changed traffic requirements: higher driving speeds and larger vehicle masses. The aim was to examine the strength and safety of the parapets used on bridges. At the same time the raised concrete central divider designed for the Lapinlahti bridge was tested. The results and pictures of the tested steel parapets listed below are from the test report edited by Sanaksenaho (1964):

- Standard pedestrian parapet
- Standard vehicle parapet
- Standard vehicle parapet for motorway
- Vehicle parapet of Lapinlahti bridge
- Low vehicle parapet with added pipe handrails

2.2.2 Test arrangements

Figure 2.2 Test vehicles were pulled by another vehicle by a cable (on the left), or pushed, when a higher speed was needed (on the right).

The parapets were manufactured at the Tuomarila repair workshop according to the drawings of the Finnish Roads and Waterways Administration. The posts of the parapets were grouted into the holes of the concrete foundation slab. The post spacing of the parapets was two metres. The height of the parapets from the top of the foundation slab was about 1.1 m in all other cases except with the low vehicle parapet with added pipe handrail where it was just over one metre.

The vehicles used in the tests were ready for scrapping. Test vehicles were pulled at the end of a 150 m long cable by another vehicle, or pushed, when a higher speed was needed (Fig. 2.2). Pushing distance was about 500 m. Pushed vehicles were steered by ropes attached to the steering wheel. A person standing on the body of the pushing truck, handled the ropes. The speed of the vehicle was measured by the odometer of the pulling/pushing vehicle. Measuring accuracy was 2…3 km/h. The speed was checked in a couple of tests by radar gun.

2.2.3 Standard pedestrian parapet

The standard pedestrian parapet was tested because, at the time, it was also used as a vehicle parapet on bridges with a raised walk along the edge of the bridge. The frame (incl. the handrail, the horizontal member at the lower edge of the parapet and posts) of the standard pedestrian parapet was made of L-65×100×9 profile. The parapet was equipped with rail infill (vertical bars 30×8 with a spacing of about 0.2 m), but as was common with pedestrian parapets of those days it had no rail. The test was conducted so that the vehicle had to climb first onto the 0.15 m high footway.

Before the impact test on the pedestrian parapet, the effect of the raised walk was tested (Fig. 2.3) with a Land-Rover all-terrain and Sisu heavy goods vehicles (HGV). The total number of tests was about 50, while the impact speed and angle were 5…50 km/h and 0…30°. The conclusion was that the significance of the raised walk as a vehicle impact energy absorber is negligible. It did not reduce the severity of the impact against the parapet. Thus it was estimated that its function is mainly to prevent the vehicle from sliding onto the footway on an icy roadway.

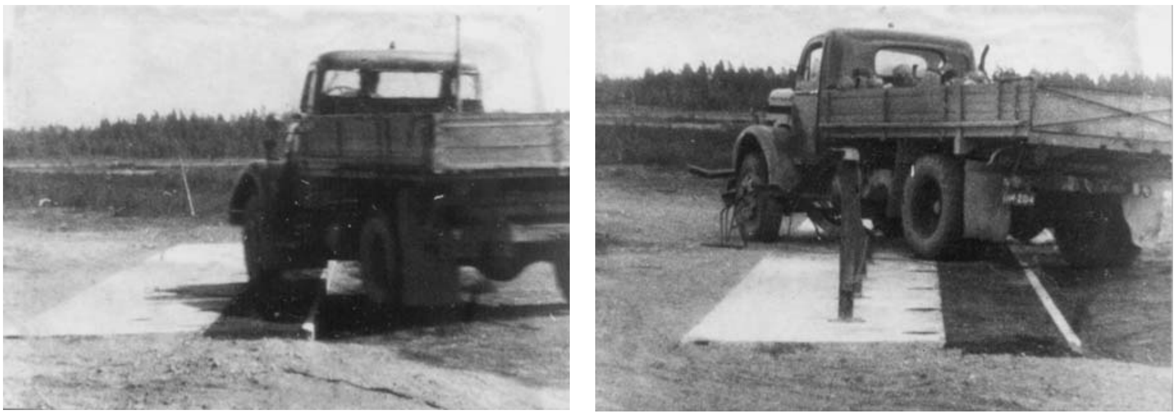

Figure 2.3 The picture on the left depicts the test arrangements of the footway before the installation of the parapet. The picture on the right shows the standard pedestrian parapet after the impact of the rigid HGV (mass 9.0 tons, speed 32 km/h and impact angle 30°).

The impact test on the standard pedestrian parapet is presented in Figure 2.3. Because of the absence of a rail, the vehicle penetrated through the parapet while the vertical bars of the rail infill caused significant damage to the tyres and nose section of the test vehicle. The posts and rivets of the joints also proved too weak. The conclusion was that the posts should be stronger and a rail should be used with parapet even with a raised walk.

2.2.4 Standard vehicle parapet

On roads other than motorways, the standard vehicle parapet was normally used vehicle restraint system on bridges without a raised walk. It consisted of handrail, posts and rail. The handrail and the posts were L-65×100×9 profiles as with the standard pedestrian parapet. The parapet was tested both with the 200×90×5 and Kohlswa rails (Fig. 2.4). A similar impact test was made on the standard vehicle parapet as on the standard pedestrian parapet only with different impact angles.

Both rails were tested with the previous impact angle of 30°. A smaller impact angles of 25° was used with the 200×90×5 rail and 20° with the Kohlswa rail. The parapets after the impact are shown in Figures 2.5 and 2.6. With the smaller impact angle, the parapets worked quite well and made the vehicle move along the parapet. Yet, with an impact angle of 25° the post nearest to the impact point suffered severe damages.

With a bigger impact angle, the capacity of the parapets was not adequate. The rails had enough strength, but the test vehicles climbed onto the parapet and were damaged beyond repair. In the case of the Kohlswa rail, the vehicle even drove through the parapet. According to the test results, the posts and rivets of the joints were too weak as in the case of the standard pedestrian parapet.

Figure 2.4 The standard vehicle parapet with the 200×90×5 (on the left) and Kohlswa rail (on the right). The picture on the right was taken after the impact of the rigid HGV with an impact angle of 20°.

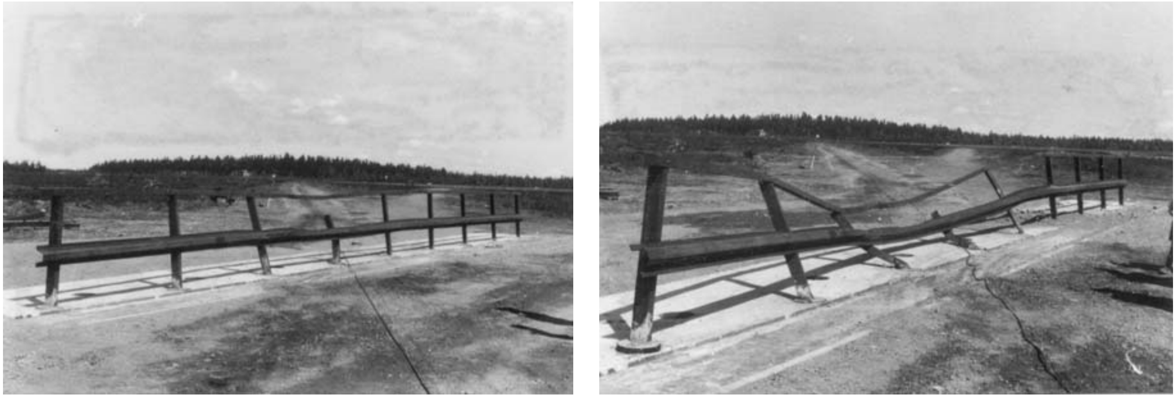

Figure 2.5 The standard vehicle parapet with the 200×90×5 rail after the impacts of the rigid HGV (mass 9.0 tons and speed 32 km/h). The parapet was tested with two different impact angles: 25° (on the right) and 30° (on the left).

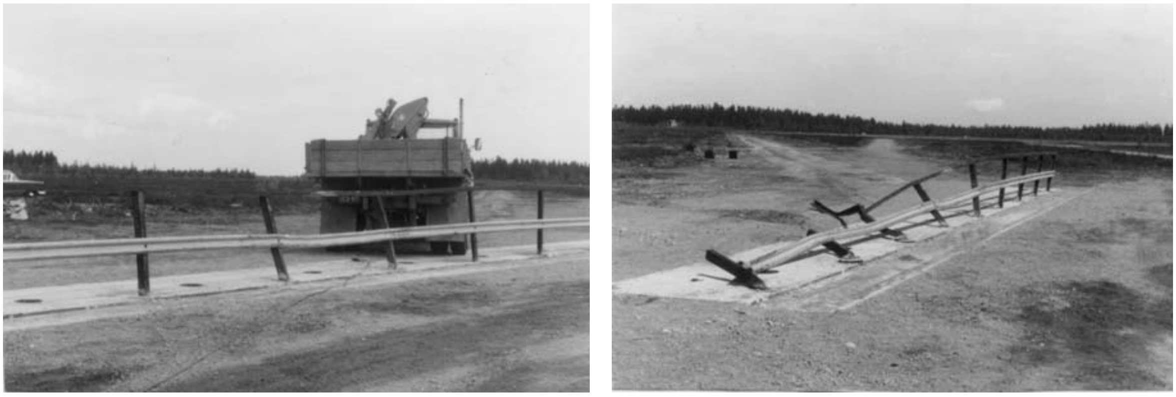

Figure 2.6 The standard vehicle parapet with the Kohlswa rail after the impacts of the rigid HGV (mass 9.0 tons and speed 33 km/h). The parapet was tested with two different impact angles: 20° (on the right) and 30° (on the left).

2.2.5 Standard vehicle parapet for motorways

The standard vehicle parapet for motorways was commonly used on motorways. It consisted of a UNP120 handrail, P101.6×101.6×9.53 posts (or pipes with concrete infilling made of two L-65×100×9 profiles) and SAG rail type A (Fig. 2.7). The parapet was tested with a car and a rigid HGV, similar to the previous tests.

Figure 2.7 The standard vehicle parapet for motorways with SAG rail type A. The picture on the right was taken after the impact of the car (mass 1.2 tons, speed 50 km/h and impact angle 30°).

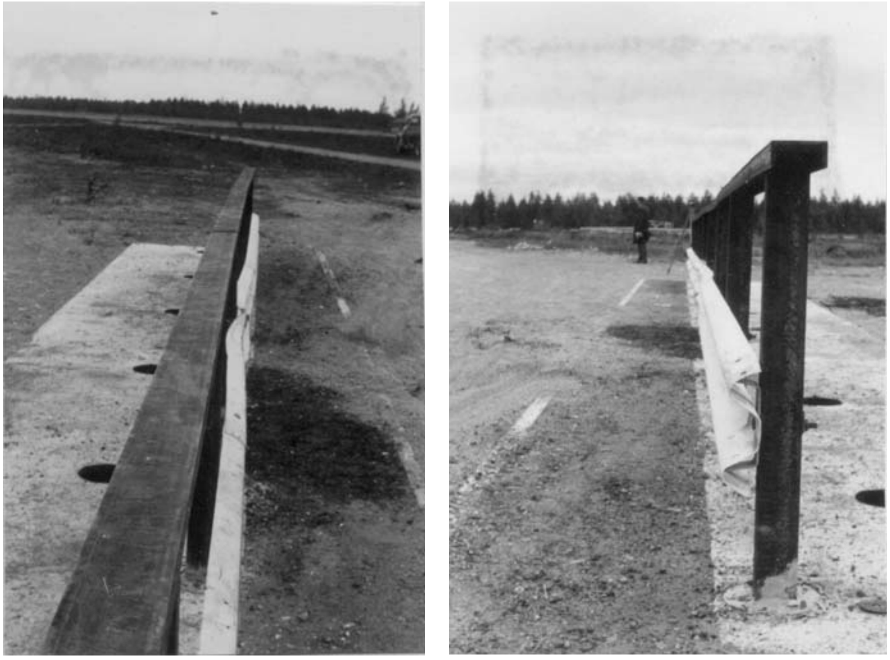

Figure 2.8 The standard vehicle parapet for motorways after the impact of the rigid HGV (mass 9.0 tons, speed 40 km/h and impact angle 25°).

The car was damaged badly in the test while there were no perceivable deformations in the parapet (Fig. 2.7). The conclusion was that the parapet was strong enough to hold the car on the bridge even with high impact speed. During the time excessive rigidity of the parapet, and the resulting high risk of severe occupant injuries, were not seen as a problem as today.

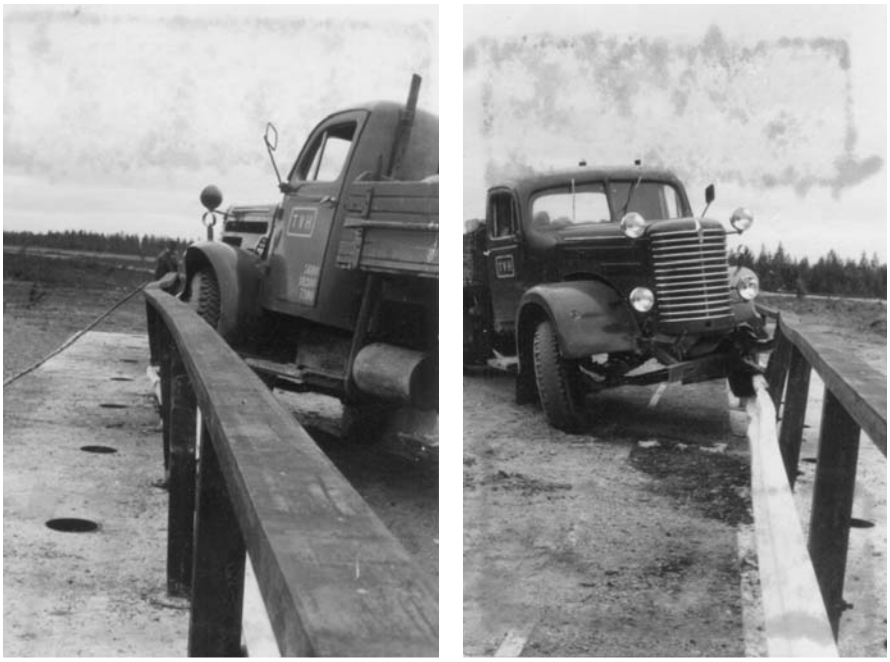

Figure 2.9 The standard vehicle parapet for motorways after the impact of the rigid HGV (mass 9.0 tons, speed 39 km/h and impact angle 30°).

The test with the rigid HGV was made with two different impact angles: 25° and 30°. Because the test was made on a vehicle parapet used on motorways, the impact speed was higher than in previous tests. With the smaller impact angle, the parapet worked well and made the vehicle move along it (Fig. 2.8). The deformations of the parapet were small, while the vehicle was damaged to the extent that it was not drivable condition.

With the bigger impact angle the deformations of the parapet were more considerable (Fig. 2.9). The test vehicle stopped against the parapet and was damaged beyond repair. The parapet, however, was strong enough to hold the vehicle on the bridge. Thus the conclusion of the tests made on the standard vehicle parapet for motorways was that it was a suitable structure to be used on motorways.

2.2.6 Vehicle parapet of the Lapinlahti bridge

Figure 2.10 The vehicle parapet of the Lapinlahti bridge (the standard vehicle parapet for motorways with the SAG rail type B and reinforced handrail and posts).

The vehicle parapet for motorways was also tested as a reinforced version which was designed to be used on the Lapinlahti bridge. The handrail was pipe made of two L-80×120×12 profiles, the posts were pipes made of two L-100×100×16 profiles and the SAG rail was type B (Fig. 2.10). The parapet was tested with the rigid HGV which was heavier and had a higher impact speed than in the tests on other parapets. The aim was to create the most severe conditions estimated to be possible in a real collision.

Figure 2.11 The standard vehicle parapet of the Lapinlahti bridge after the impact of the rigid HGV (mass 12.5 tons, speed 60 km/h and impact angle 28°).

The tested parapet was strong enough to hold the vehicle on the bridge (Fig. 2.11). Its deformation was moderate, while the vehicle was damaged beyond repair. The parapet was although considered uneconomical. It was too rigid and too strong for the traffic of that time. Based on the tests results, the standard vehicle parapet for motorways was recommended as a rule. A stronger version, like the vehicle parapet of the Lapinlahti bridge, was expected to be required in the future as driving speeds and vehicles masses increase.

2.2.7 Low vehicle parapet with added pipe handrails

Figure 2.12 The low vehicle parapet with the added pipe handrails just before and after the impact of the rigid HGV (mass 9.0 tons, speed 50 km/h and impact angle 30°).

The last tested parapet was the low vehicle parapet with added handrails made of P60×3 pipe. The frame of the low vehicle parapet consisted of INP 140 posts and Pass rail type A. The parapet was tested by a rigid HGV and an impact angle of 30°, like the standard vehicle parapet for motorways but with a higher speed (Fig. 2.12). The test vehicle stopped against the parapet, but the parapet bent partly against the ground and the rails broke off.

According to the test results, the parapet was not strong enough to be used as a vehicle parapet — at least on motorways. A safety barrier on a high embankment with a footway beside it was thought to be a suitable application of the tested structure. The bending of the pipe post of the added handrail structure was, however, estimated to be unnecessary additional cost.

2.3 Present state of affairs

2.3.1 Overview

There are about 20,000 bridges in Finland, of which about 70 per cent are administered by Finnra. The total number of bridges carrying road traffic is about 17,000. Each year about 250 new bridge projects are completed, of which railway bridges represent about 15 per cent and a little over 5 per cent are built only for pedestrian traffic. The rest, a little fewer than 200 bridges, are for road traffic and thus require safety barriers. A major share consists of small culvert-type structures, which are classified in Finland as bridges when the clear span is two metres at the minimum. The vehicle restraint systems used with such bridges are modifications of the safety barriers on the road.

Thus, only about 120 new bridge projects with vehicle parapets are implemented each year. The average length of a vehicle parapet was estimated at 60…80 m by dividing the known total area of built bridge decks by half of the estimated average effective width of the bridges. The length estimation is not exact, but a parapet manufacturer, who launches about 100 bridge projects annually, arrived at the same value by analysing their completed projects. The total length of constructed vehicle parapet per year can thus be estimated at about 8.4 km.

The present standard vehicle parapet of Finnra is normally used structure on the road bridges administered by Finnra and others (e.g. municipalities), but other kinds of vehicle parapets conforming to the given design requirements are also used on a small scale.

2.3.2 Standard vehicle parapet of Finnra

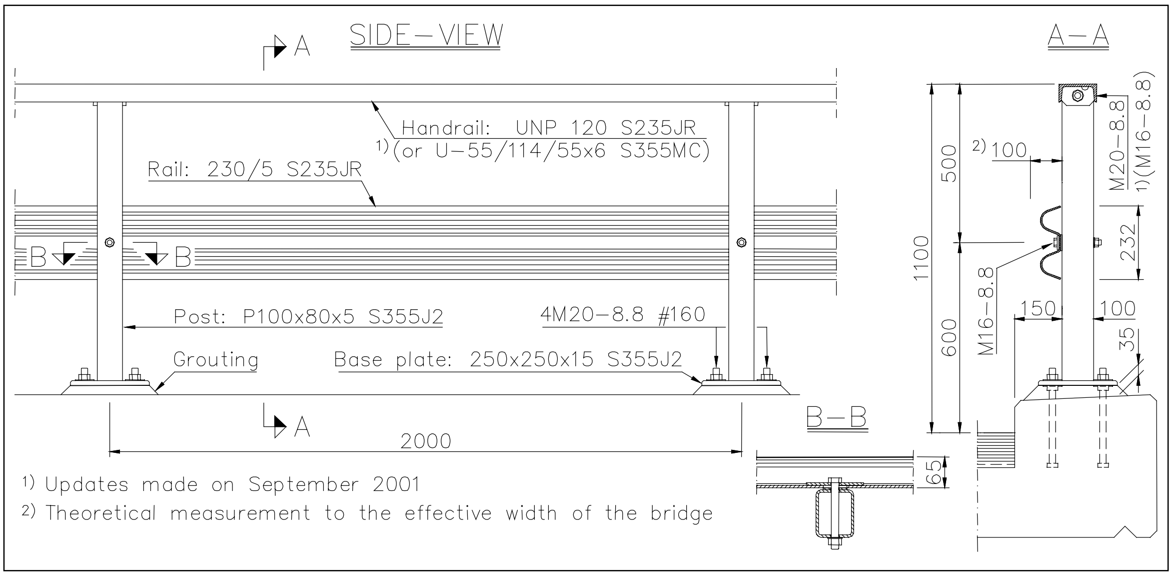

Figure 2.13 General drawing of the present standard vehicle parapet of Finnra (High vehicle parapet).

The present standard vehicle parapet of the Finnish Road Administration, called the High vehicle parapet, is based on impact tests made in 1964. It resembles mainly the old standard vehicle parapet for motorways, and thus also poses a high risk of severe occupant injuries in a light vehicle collision. Pedestrian parapets are no longer used as road vehicle parapets on bridges with a raised walk along the edge of a bridge. Nor are low vehicle parapets nowadays allowed on the edges of bridges to be built.

Here, the term present is used even though it is not quite accurate anymore, because the new Finnish standard vehicle parapets, developed during the project described in this thesis, are already in use. A general drawing of the structure, with the updates made during the development project of the new standard vehicle parapets, is presented in Figure 2.13. Standard drawings of the High vehicle parapet (R15/DK 1-1...14, R15/DK 4-2 and Ko-2484) can be found on the Internet (www.tiehallinto.fi/sillat/tyyppipiirustukset/sillanosat/luettelo.htm). The impact test photos of the structure are shown in Chapter 4.2.1.

The hot galvanised parapet is 1.1 m high from the road surface and, if installed on the high edge beam, weighs about 38 kg/m (expansion joints excluded). It is a rigid structure consisting of pipe posts with a spacing of 2.0 m, 230/5 rail (Rautaruukki Oyj) and U-profile as a handrail. The U-profile is normally the hot-rolled UNP 120. An alternative is the corresponding cold-rolled profile developed for use with the new Finnish vehicle parapets.

Posts are normally anchored to the bridge deck by bolts. Previously they were generally grouted into the holes of the edge beam, but the practise has been abandoned due to durability problems: heavy steel corrosion occurs in the area where the posts meet the edge beam due to water and salt, which is used as an antiskid treatment in winter, and the alkalinity effect of concrete on the coating of the post. The latter was more significant earlier when the protection of the posts against corrosion was provided only by paint. Moreover, a post of large cross-section requires big holes, where shrinking of the grouting might cause cracks through which water can pass into the holes. Freezing water together with the capacity reduction effect of the holes can lead to the edge beam breaking.

2.3.3 Vehicle parapet design

Finnish design requirements aim to secure adequate structural capacity of the parapet against collision by a heavy vehicle. There are no observations about the estimations of light vehicle impact severity (e.g. the limits for rigidity values). Disregard for the risk of occupant injuries has led to too rigid structures, which also applies to present standard vehicle parapet. During the transition period, before the implementation of Standard EN 1317, according to Finnra, vehicle parapets on new bridges are either (Finnish National Road Administration 1995):

- Built in accordance with Finnish standard drawings
- Quality approved in Finland
- Impact-tested in compliance with the current version of the European standard and suitable for Finnish conditions
- Approved in some other country and suitable for Finnish conditions, or
- Modified based on Finnish standard drawings

So far, only the first alternative has been widely selected. The last one, which means that the standard vehicle parapet is modified to suit the aesthetics of a certain bridge, has been chosen in a few cases (Fig. 2.14). The modification of the present standard vehicle parapet of Finnra is done by replacing a structural member of its frame by a profile providing the same or a higher design value for force and moment resistances, which are (1.0 as the partial safety factor of steel):

- Handrail:
  - 400 kN tensile force (incl. expansion joints)
  - 14 kNm bending moment (about the vertical direction)
- Rail:
  - 400 kN tensile force (rail)
  - 127 kN tensile force (expansion joints)
  - 5.8 kNm bending moment (about the vertical direction)
- Posts:
  - 350 kN shear force (transverse to the longitudinal direction of parapet)
  - 19 kNm bending moment (about the longitudinal direction of parapet)
  - 13.5 kNm torsion moment

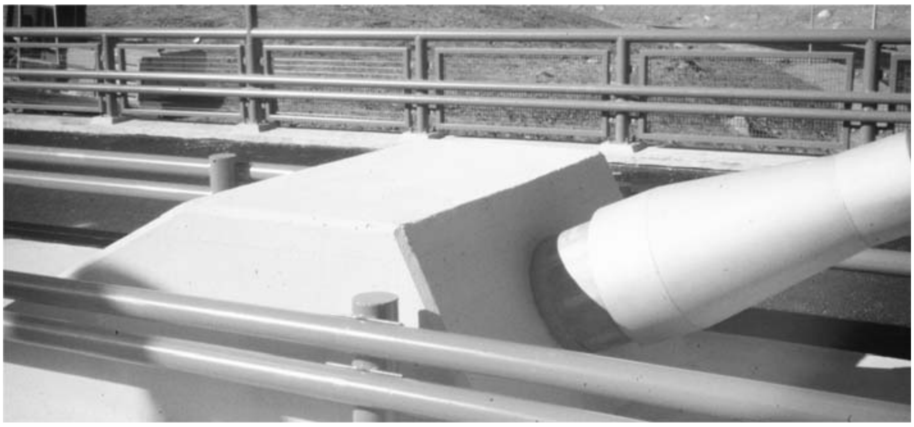

Figure 2.14 The vehicle parapets of the cable-stayed Lippo flyover in Lempäälä, Finland (2000). Pipe frame parapets are based on Finnish standard drawings of the vehicle parapet (Courtesy of A-Insinöörit Oy).

If a vehicle parapet is built on a road bridge administered by someone else than Finnra, different design requirements from the above can be applied. Design can be according to the publication "Directions of actions on structures" (Association of Finnish Civil Engineers 2002). Its requirements for safety barriers have been similar since the beginning of the 1980's. Safety barriers are designed by using a 0.6 m long static lateral knife-edge load affecting on the elevation 0…1.0 m above the road surface with the influence of the biggest single wheel load of the traffic area. The value of the wheel load is defined in the publication "Traffic loads on bridges" (Finnish National Road Administration 1999d). The maximum characteristic value 130 kN of the load is achieved by using Load Model 3 of Traffic Class I.

According to the publication "Directions of actions on structures", the structural calculation using the knife-edge load is not needed, if the following statements are fulfilled: the handrail of the safety barrier (incl. expansion joints) has at least 500 kN tensile force resistance, it is about one metre from the road surface, and the post spacing is two metres at the maximum. Safety barriers, whose lateral distance from the road edge is 1.5 m or less, must be equipped with a steel rail at a vertical distance of about 0.5 m from the road surface. The handrail of the safety barrier must be anchored diagonally if the length of the safety barrier is less than 10 m.

2.4 Standard EN 1317: Road restraint system

2.4.1 Contents of the standard

The European standard consists of the following parts under the general title: Road restraint system.

- EN 1317-1:1998 Road restraint system. Part 1: Terminology and general criteria for test methods
- EN 1317-2:1998 Road restraint system. Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers
- EN 1317-3:2000 Road restraint system. Part 3: Crash cushions – Performance classes, impact test acceptance criteria and test methods for crash cushions

- ENV 1317-4:2001 Road restraint system. Part 4: Impact test acceptance criteria and test methods for terminals and transitions of safety barriers
- prEN 1317-5 Road restraint system. Part 5: Durability criteria and evolution of conformity
- prEN 1317-6 Road restraint system. Part 6: Pedestrian road restraint system

Parts 1…3 also have the status of Finnish national standards: SFS-EN 1317-1:1998, SFS-EN 1317-2:1998 and SFS-EN 1317-3:2001.

2.4.2 Impact tests according to the standard

Overview

The requirements and methods of full-scale impact tests of safety barriers are specified in parts 1 and 2 of Standard EN 1317. Requirements presented in this chapter have been edited from SFS-EN 1317-1:1998 and SFS-EN 1317-2:1998 (reprinted with the permission of the Finnish Standards Association).

Containment levels and vehicle impact test criteria

The standard consists of several containment levels of safety barriers. Different levels and vehicle impact test criteria of the permanent safety barriers are presented in Table 2.1. Temporary safety barriers are not dealt with here. The evaluation of safety barriers with a higher containment level will require carrying out two different tests: a test using a heavy vehicle (bus or HGV) for estimating the maximum level of containment, and a test using a car in order to verify that the satisfactory attainment of the maximum level is also compatible with the safety of the light vehicle. A successfully tested installation at a given containment level shall be considered as having met the test condition of a lower level.

All vehicles that satisfy the vehicle specifications requirements list (e.g. the values and tolerances of masses, dimensions and centre of gravity locations) of the standard can be used. The impact speed limit deviation at the test shall be -0 … +7 per cent. The corresponding limit for impact angle depends on impact speed and shall be -1 … +1.5º.

Table 2.1 The containment levels and vehicle impact test criteria of the permanent safety barriers according to Standard EN 1317.

Containment levels		Acceptance test	Impact speed [km/h]	Total vehicle mass [kg]	Impact angle [°]	Type of vehicle
Normal	N1	TB 31	80	1 500	20	Car
	N2	TB 11	100	900	20	Car
		TB 32	110	1 500	20	Car
Higher	H1	TB 11	100	900	20	Car
		TB 42	70	10 000	15	Rigid HGV
	H2	TB 11	100	900	20	Car
		TB 51	70	13 000	20	Bus
	H3	TB 11	100	900	20	Car
		TB 61	80	16 000	20	Rigid HGV
Very high	H4a	TB 11	100	900	20	Car
		TB 71	65	30 000	20	Rigid HGV
	H4b	TB 11	100	900	20	Car
		TB 81	65	38 000	20	Articulated HGV

Test vehicle and safety barrier behaviour requirements

The centre of the vehicle shall not cross the centreline of the deformed system. The vehicle shall remain upright during and after impact, although moderate rolling, pitching and yawing are acceptable. The vehicle shall leave the safety barrier after impact so that the wheel tracks do not cross the line parallel to the initial traffic face of the safety barrier, at a distance A plus the width of the vehicle plus 16 per cent of the length of the vehicle within a distance B from the original intersection (break) of the wheel track with the initial traffic face of the safety barrier. Distance requirements for exit box criterion of the light vehicle are: A = 2.2 m and B = 10.0 m. The values of the heavy vehicles are double as much.

The safety barrier shall contain and redirect the vehicle without complete breakage of the principal longitudinal elements of the system. No major part of the safety barrier shall become totally detached or present an undue hazard to other traffic or pedestrians. Elements of the safety barriers shall not penetrate the passenger compartment of the vehicle. Deformations of, or intrusions into, the passenger compartment that can cause serious injuries are not permitted. Ground anchorages and fixings shall perform according to the design of the safety barrier system.

The deformation of the safety barriers during impact tests is characterised by dynamic deflection and working width. It is important that maximum deformation should be compatible with the available space or distance behind the system. Dynamic deflection (D) is the maximum lateral dynamic displacement of the side facing the traffic of the safety barrier. Working width (W) is the distance between the side facing the traffic of the safety barrier before the impact and the maximum dynamic lateral position of any major part of the safety barrier or vehicle. Working width is classified into eight levels W1…8 with a range of maximum values of W = 0.6…3.5 m.

Impact severity requirements

Two different alternative impact severity levels are defined in the standard. Level A affords a greater level of safety for the occupants of an errant vehicle than B, but either one of them can be chosen. The vehicle occupant impact severity assessment indices and their requirements are:

- Acceleration severity index ASI $\leq \begin{cases} 1.0 & \text{, level A} \\ 1.4 & \text{, level B} \end{cases}$
- Theoretical head impact velocity THIV $\leq$ 33 km/h
- Post-impact head deceleration PHD $\leq$ 20 g (g = 9.81 m/s^2)

The above test parameters are values of a point in the vehicle centre of gravity computed from a light vehicle test. The coordinate axes of the vehicle body used in measured data during the impact are x (longitudinal), y (transversal) and z (vertical).

ASI is a non-dimensional quantity, which is a scalar function of time having only positive values. The more ASI exceeds unity, the more the risk for the occupant exceeds the safety limits; therefore the maximum value attained by it in a collision is assumed as a single measure of severity. ASI is computed with the following equation:

$$\mathrm{ASI} = \sqrt{\left(\frac{\bar{a}x}{\hat{a}x}\right)^2 + \left(\frac{\bar{a}y}{\hat{a}y}\right)^2 + \left(\frac{\bar{a}z}{\hat{a}z}\right)^2} \quad \text{, where} \tag{2.1}$$

ā = Components of the acceleration along the axes x, y and z. Values are averaged over a moving time interval of 50 ms.

â = Limit values for the components of the acceleration. The limit accelerations are interpreted as the values below which passenger risk is very small (light injuries, if any). For passengers wearing safety belts, the generally used values are âx = 12 g, ây = 9 g and âz = 10 g.

The higher limit of the value of ASI at level B, which is the only difference between the impact severity levels of the standards, was developed originally for concrete wall vehicle restraint systems. Improved measurement accuracy has led to a situation where the concrete safety barriers exceed the limits and the steel safety barriers barely fulfil the requirement of level B. It has been suggested that in the future the new level without any limit value for ASI may be used at least for concrete vehicle restraint systems.

THIV is a magnitude of the velocity of the occupant's head striking against a surface within the interior of vehicle. During the impact of the vehicle against the vehicle restraint system the vehicle is assumed to move only in a horizontal plane. The occupant is considered to be a freely moving object (head) that, as the vehicle changes its speed during contact with the vehicle restraint system, continues moving until it strikes against a surface. The notional impact surface inside the vehicle is assumed to be flat and perpendicular to the vehicle x- and y-axes. The distances of such surfaces from original head position (flail distances) are laterally on both sides. Its standard values are $D_x = 0.6$ m and $D_y = 0.3$ m.

The head is presumed to remain in contact with the notional impact surface inside the vehicle during the remainder of the impact period. In so doing it experiences the same levels of acceleration as the vehicle during the remaining contact period. PHD is a maximum value of the post-impact head resultant acceleration computed from 10 ms average of the measured components along the axes x and y.

The vehicle occupant impact severity assessment indices ASI, THIV and PHD measure the same impact phenomenon from different aspects. Any one of them can be a determinant depending on the tested structure. The calculation of PHD starts after the calculation of THIV ends; when the head of the occupant hits the notional impact surface inside the vehicle. ASI is calculated throughout the collision and is averaged over the moving time interval like PHD, but the size of the time interval is longer. Thus it does not react as sensitively to changes in the components of acceleration along the x- and y-axes as PHD, but it includes also the component along the z-axis.

3 DEFINITION OF THE PROBLEM

3.1 Aim of the study

The aim was to prove that vehicle parapets conforming to the impact test acceptance criteria of Standard EN 1317 can be developed at a reasonable cost by combining experience and calculation analyses with full-scale impact tests. The goal was to improve road safety by developing impact-safer vehicle parapets. The development of new higher containment level structures was emphasised in the process, but impact-safer modifications of the present vehicle parapet were also examined.

3.2 Objectives of new impact-safer vehicle parapets

3.2.1 Overview

The project described in this thesis started at the end of 1999 by the definition of the objectives for the development of new impact-safer vehicle parapets. It was done by studying and comparing the present standard vehicle parapet of Finnra and vehicle parapets conforming to the European standard.

3.2.2 Vehicle parapets conforming to Standard EN 1317

Introduction

During the time of the vehicle parapet comparison there were only few constructions whose compliance with the requirements of the standard was verified. Two structures of different type were chosen for more detailed examination. One was a massive frame equipped with deformation elements while the other was aesthetically light but ductile.

Safety-Rail of Volkmann & Rossbach

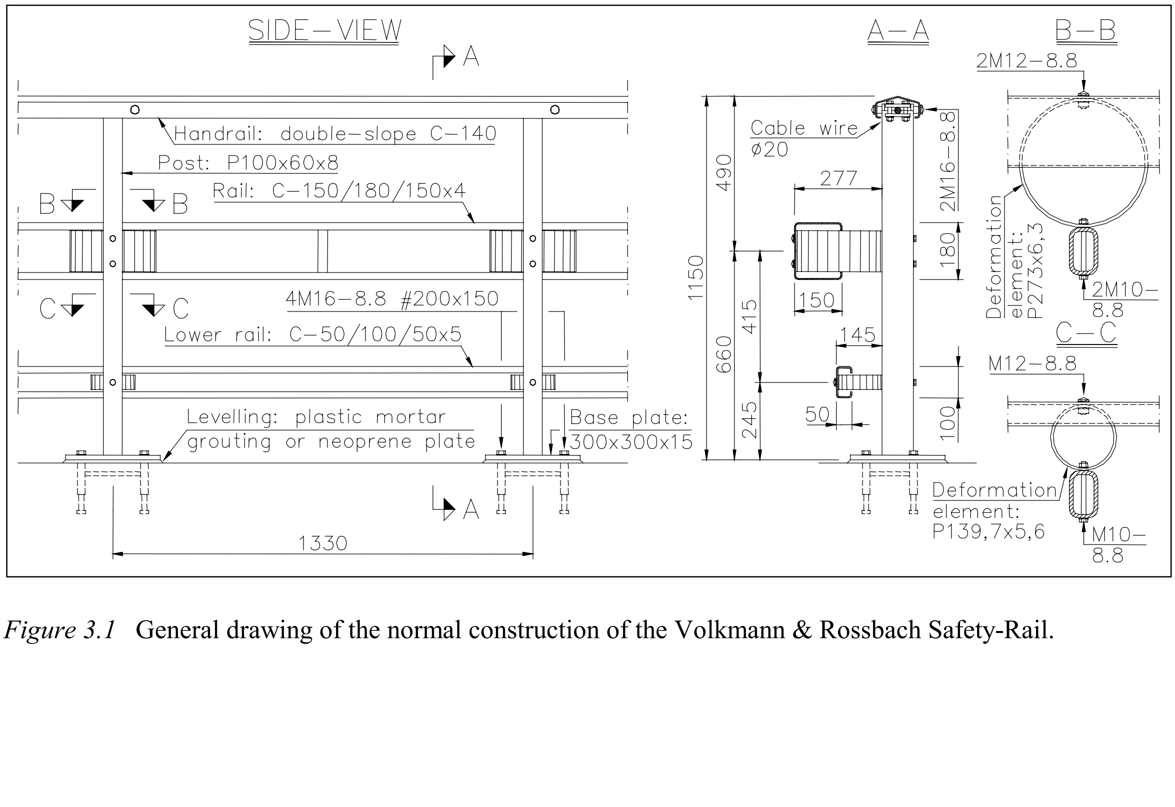

Figure 3.1 General drawing of the normal construction of the Volkmann & Rossbach Safety-Rail.

Figure 3.2 Volkmann & Rossbach Safety-Rail installed on the Humalajoki flyover in Kuopio, Finland (2000) (Courtesy of Finnra).

The normal construction of the Safety-Rail presented in Figure 3.1 is the containment level H2 structure of Volkmann & Rossbach GmbH & Co. The construction is protected by patent. During the development project of the new Finnish standard vehicle parapets the Safety-Rail was used on a motorway in Kuopio to gain knowledge about its functioning in Finnish conditions (Fig. 3.2).

The hot galvanised parapet is a 1.15 m high, massive and rigid construction. It weighs about 60 kg/m (expansion joints excluded). The parapet consists of pipe posts with dense spacing, box beam profiles and a cable wire inside a handrail. The posts are anchored to the bridge deck by bolts and screw sockets. The frame has enough strength to sustain a collision by a heavy vehicle, but its massiveness leads to a rigidity problem when hit by a light vehicle.

To ensure that occupant impact severity is low enough, the rail and lower rail have been equipped with big deformation elements made of pipes, which widen the construction considerably. The parapet is also marketed without the deformation elements of the rail as the “space saving construction” which does not meet the requirements of containment level H2.

Standard vehicle parapet of SNRA

The standard vehicle parapet of the Swedish National Road Administration (SNRA) installed on a high edge beam is a containment level H2 structure when equipped with the W rail (Fig. 3.3). The impact test photos with it are shown in Chapter 4.2.2. The functioning of the parapet, if installed on a low edge beam or equipped with the alternative rail profile, is analysed with the Nordic simulation application described in Chapter 4.3.

The Swedish standard vehicle parapet is hot galvanised, 1.2 m high from the road surface, and, if installed on a high edge beam, weighs about 45 kg/m (expansion joints excluded). It consists of posts with a spacing of 1.8 m, a W rail (306/3) and UNP 120 as a handrail. During the development project of the new Finnish standard vehicle parapets a modified version of the Swedish standard vehicle parapet was used in Helsinki (Fig. 3.4). The structure was equipped with open tubular section rails (AB Varmförzinkning) approved in Sweden to be used instead of the normally used W rail. The replacement of the rail was based on simplified calculations, which was at the time acceptable method. The fixing to the edge beam was made as with the Finnish standard vehicle parapet.

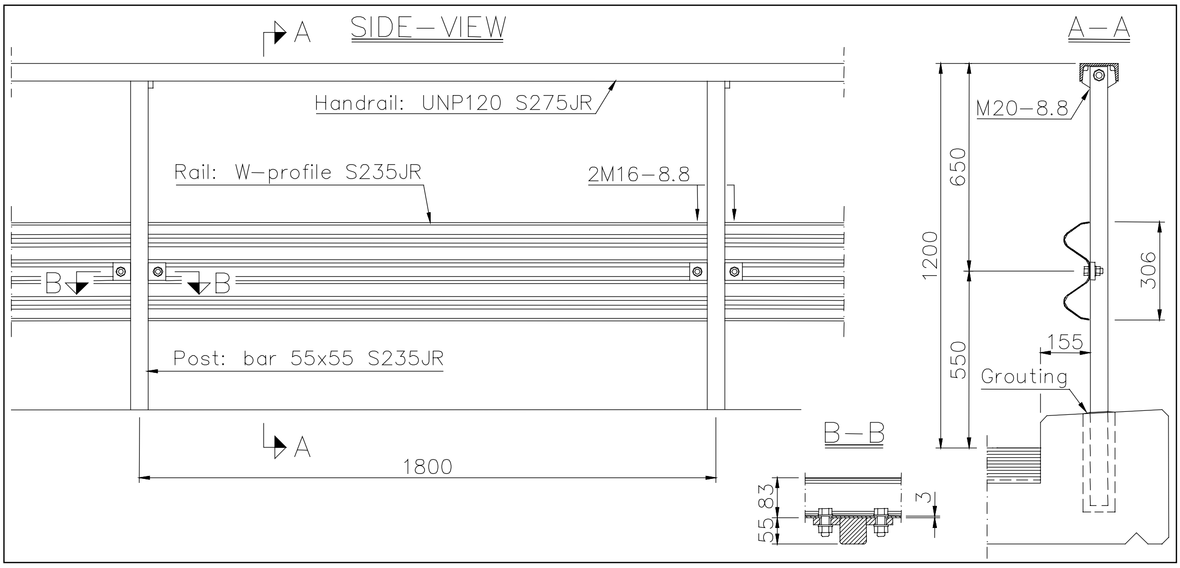

Figure 3.3 The general drawing of the standard vehicle parapet of SNRA.

Figure 3.4 Modified Swedish standard vehicle parapet installed on the Salmisaari flyover in Helsinki, Finland (2000) (Courtesy of YS-Konsultit Oy).

The Swedish standard vehicle parapet is a light structure. Its posts are ductile solid steel bars of relatively low bending stiffness and yield value of bending moment. Thus it bends adequately in a light vehicle impact, but will not break in a heavy vehicle collision. Still the posts have enough strength to prevent damages caused by snow clearance unlike the W rail, whose wall thickness is too small. Due to the small thickness the Kohlswa-profile (160/6) is used instead of the W rail in the northern part of Sweden. It weighs about as much, but is smaller and made of two times thicker plate.

The posts are normally grouted into bored holes, but bolt fixing is also used. The problems occurring with the present Finnish standard vehicle parapet with the grouting of the posts into the holes are less meaningful with the Swedish construction due to the small holes and the solid cross-section of the posts.

3.2.3 Object setting

The new Finnish standard vehicle parapet types, to be used on the main roads, were named Finnra H2 vehicle parapets. The objectives for their development were defined to be:

- Containment level H2
- Narrow construction
- Aesthetically pleasing and open structure with finished details
- High enough to protect bicycle and pedestrian traffic
- Able to withstand small impacts without notable damages

Containment level H1 is the lowest acceptable level of a permanent safety barrier in a test with a heavier vehicle than the car, and so it was considered to be the lowest suitable level for the safety barrier on a bridge. Containment level H1 was estimated to be adequate outside the main roads, but for the main roads the higher H2 level was chosen. The next level, H3, was estimated to require too massive structures. Containment level H2 was chosen also, because it is the level that the other European countries are also trying to achieve. In Sweden SNRA has required (Swedish National Road Administration 2002) that from the beginning of 2003 new vehicle parapets must meet containment level H2 at the minimum.

At containment level H2, during the first phase of the collision, the lateral kinetic energy (T) from the heavy vehicle perpendicular to the barrier, computed with equation 3.1, is over two times higher than at H1. The equivalent kinetic energy at H3 is almost four times higher than at H1.

$$T = \frac{m\,(v \sin\alpha)^2}{2} \quad \text{, where} \qquad (3.1)$$

m = total vehicle mass (kg)
v = impact speed (km/h)
α = impact angle (°)

Because the present standard vehicle parapet of Finnra did not conform to the European standard in the light vehicle collision, and only just in the heavy vehicle collision of level H1 (see Chapter 4.2.1), it was obvious that it was not a suitable frame to be used in the development of the level H2 vehicle parapet. It was nevertheless decided to reduce its rigidity by modifying the deformation elements of the tested parapet. The object was to meet the requirements of the standard also in a light vehicle collision. The developed Finnra H1 vehicle parapets were designed to be used mainly in the rehabilitation and repair of bridges where there is the present standard vehicle parapet of Finnra.

The whish was that the Finnra H2 vehicle parapets would be made narrow. A wide construction requires a wider and thus more expensive bridge deck. A wide vehicle parapet may also have an unfavourable effect on snow removal. A wide construction can also mean a higher safety risk for pedestrians. The parapet may form a “climbing frame”, and wide rails may tempt people to walk on them. The height of the parapet was also an important safety aspect with respect to bicycle and pedestrian traffic. There have been bicyclist accidents that have shown that the present standard vehicle parapet is a little too low for protection of bicyclists.

An easier way to develop a new containment level H2 vehicle parapet would be to develop a massive structure and improve its performance in a light vehicle collision by equipping it with energy absorbing devices. The result would be a heavily built and expensive structure. A more economic and aesthetically more pleasing, light and open structure can be achieved by designing the structure so that the frame bends adequately, but has enough strength against breaking. In the later case chosen here, design is harder. A heavy vehicle collision requires a rigid structure with high strength, while the requirements of a light vehicle collision are the opposite: the narrow target is somewhere in the middle. The need to withstand small impacts, snow clearance, etc. without notable damages also complicates the meeting of structural rigidity and strength requirements.

Setting finished details as an objective meant that the joints and components of the developed parapets needed to be aesthetically well designed, while fabrication and installation requirements also had to be taken into account. Due to the emphasis on the aesthetic of the structure, different rail alternatives were developed to be used with the new standard vehicle parapets.

4 IMPACT TEST METHODS AND PREVIOUS TESTS

4.1 Overview

According to Standard EN 1317, the impact performance of safety barriers is tested by full-scale impact tests where actual vehicles collide with a full-size safety barrier construction. Besides full-scale testing, computer simulation is also used, and its utilisation is increasing as its reality accuracy improves and cost falls. At the moment, it is used as a design tool for structures whose compliance with the European standard is later verified by full-scale impact tests. The current version of Standard EN 1317 does not contain any specification concerning computer simulation. It is estimated that the next revision of the standard may contain a list of simple cases, where calculations like computer simulation can be used for simple modification of the impact-tested safety barriers, and thus get approval without new full-scale tests.

The developed computer simulations of the impact moment, described in Chapter 5.1.3, were simplified systems based on the finite element method (FEM). For example the FE system used to analyse the capacity of the vehicle parapet subject to the heavy vehicle impact consisted of a model made of nonlinear 3D beam elements and the static force as the load. The analysis method utilised previous full-scale impact tests for defining the static load that corresponds to the actual dynamic impact load as well as possible. The previous tests concerned were the impact tests made on Finnish and Swedish standard vehicle parapets, presented in the next chapter, according to the European standard before the development of the new Finnish standard vehicle parapets.

A more accurate finite element model is achieved by modelling also the vehicle and by using surface and volume elements. Although a more precise FE model is also more complicated, its solving requires lots of CPU-time and the factors of uncertainty of the calculation may increase. For example, a small misinterpretation in the modelling of the wheel suspension of the vehicle can lead to wrong conclusions about the impact performance of the parapet.

One example of more reality-accurate FE system is the Nordic simulation application presented in Chapter 4.3. The Finnish Road Administration and the Norwegian Public Roads Administration have financed part of the development project, while the Swedish National Road Administration has been the main investor. The encoding has been done simultaneously with the development of the new Finnish standard vehicle parapets. The simulation application can be used, for instance, in development work where the vehicle parapet is subject to small modifications and comparison of different alternatives is needed. The Nordic simulation application has played an important role in the development of the Swedish and Norwegian vehicle parapets.

The cost of using the Nordic simulation application was asked several times during the Finnish development project. The first time in 2001 the cost was almost as high as that of a full-scale impact test, which has been quite reasonable in Finland. In 2002 the cost of the car test halved and the cost of the bus test was reduced by one third. Yet, it was regarded as too expensive because the current version of the standard nevertheless requires full-scale tests. Finally, in 2003 the application was tested as part of the development of the Finnish standard vehicle parapets. Full car simulations, at only one third of the cost of two years earlier, were made on the Finnra H2 vehicle parapet with a rail similar to the rail of the present standard vehicle parapet.

4.2 Previous impact tests

4.2.1 Finnish standard vehicle parapet

Introduction

Table 4.1 Impact tests on the present Finnish standard vehicle parapet.

Test n:o	Tested parapet	Test date	Acceptance test
1	High vehicle parapet of Finnra	22.10.98	TB 61
2	High vehicle parapet of Finnra, modified	20.05.99	TB 42
3	High vehicle parapet of Finnra, modified	10.06.99	TB 11

The Finnish Road Administration conducted three impact tests in 1998 and 1999 (Table 4.1) consistent with Standard EN 1317 to determine the containment level of the present standard vehicle parapet. The Laboratory of Highway Engineering, Helsinki University of Technology (HUT), was the testing laboratory. The tests were organised at an airfield in Pori, Finland. The heavy vehicle test of level H3 was done first because the tested High vehicle parapet was estimated to conform to that level, at the maximum.

The results of the first test revealed the capacity problem of the parapet. Thus the next heavy vehicle test was done according to containment level H1, which was considered the lowest suitable level. The functioning of the parapet in Test 1 showed that the structure does not always have enough strength to resist even a level H1 heavy vehicle collision without modifications. Thus, before another test, the rail was equipped with deformation elements designed to work as impact energy absorbing devices. After the narrowly successful Test 2 the modified High vehicle parapet was also tested with the light vehicle to verify that the risk of vehicle occupant injuries was sufficiently low.

The results of the impact tests presented here are based on test reports edited by Valtonen & Laakso (1999). The impact moment photos are still frames of series of high speed camera photos. Freeze points in each separate case were selected for this thesis so that the pictures visualise the nature and severity of the collision as well as possible.

Test arrangements

Figure 4.1 Pulling of the light vehicle and pushing of the rigid HGV (Courtesy of Finnra).

The vehicle restraint systems were manufactured and installed by TTP-Yhtiöt Oy (at the time Terästyöpaja Oy) according to drawings of Finnra. Excavation and concrete work was done by the Finnish Road Enterprise (at the time the Road Production division of Finnra). The total length of the tested vehicle restraint systems was 48 m, including a 28 m long vehicle parapet and 10 m long end treatments of the vehicle parapet at both ends of the structure, in tests with an impact angle of 20°. In Test 2, which was the only test with the smaller impact angle of 15°, the structure and the vehicle parapet were four metres longer.

The end treatments of the vehicle parapets consisted of six-metre long transition and four-metre long terminal parts. For the first four metres of the transitions, a handrail was anchored diagonally to the rail, and the diagonal anchoring of the rail into the ground, in turn, functioned as terminals of the structures. The posts of the vehicle parapet were anchored to the concrete foundation slab by bolts. The slab represented a bridge deck with a low edge beam. The low edge beam, which is nowadays rarely used, allows water to run freely over the edge. The slab was 3.00 m in width, 0.43 m deep and 29.00 m in length in Tests 1 and 3. Test 2 involved a longer slab at a different angle to the test track.

The inspected and roadworthy test vehicles were in order of weight: Peugeot 205, Ford D-1110 and SISU SR220 CKH-6×2. Concrete slabs were used as ballast (3.45 tons in Test 1 and 5.75 tons in Test 2) on truck bodies to reach the total mass requirement of the test vehicles. The light vehicle was pulled and the heavy vehicles were pushed against the vehicle parapets by the HGV (Fig. 4.1). The speed of the vehicles was initially measured by a radar gun in situ and later verified by analysing high speed camera photos.

The acceleration of the car was effected by the pulling vehicle, attached to the car by a cable, which drove towards the car on the other side of the test track. At the end of the track was a 4 to 1 reduction gear of through which the cable was strung. Due to the reduction, there was no need to shift the gears of the pulling vehicle during driving. The bolts of the joint between the triangular strut frame, moving on the rail of the test track, and the car snapped when the strut frame hit the shock absorber at the end of the rail. After that the car travelled freely towards the parapet. To ensure that the direction of travel was sustained, a small weight was attached to the steering wheel of the car. The pushed heavy vehicles were guided (steering, breaking) by remote control. The push rod between the vehicles had a sleeve joint with a butt connection.

Test 1 (TB 61)

Figure 4.2 Impact sequence, view from the front (Courtesy of HUT).

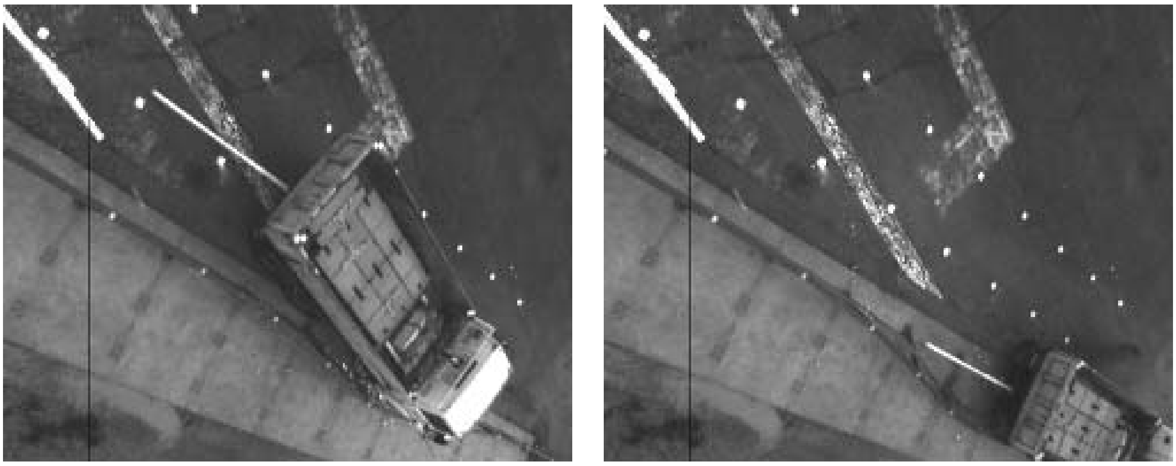

Figure 4.3 Impact sequence, view from above (Courtesy of HUT).

Figure 4.4 Deformation of the vehicle parapet after the impact (Courtesy of HUT).

The rigid HGV weighing 16.36 tons collided against the High vehicle parapet of Finnra with 70 km/h impact speed (Figs. 4.2 and 4.3). Speed was measured to be 80 km/h, which is the minimum approved value according to the standard, with a radar gun just before the crash, but a more precise analysis of the high speed camera photos gave a lower value. The impact point was four metres past the designed point due to loss of remote control of the vehicle just before the crash; thus the impact angle was also less than the desired 20º.

Even though the impact speed and angle was less than designed, the posts past the impact point broke off from the base plates and the parapet bent against the ground (Fig. 4.4). After the impact the parapet made the vehicle move along it. The left front wheel did not cross the line of the parapet until the vehicle parapet ended. The rear end of the vehicle collided heavily with the vehicle parapet and went over it, while the vehicle nose pushed the parapet down. The HGV was not in running condition after the test.

Test 2 (TB 42)

The tested parapet was a modified version of the High vehicle parapet used in Test 1. Its rail was equipped with a 170 mm high pipe deformation elements P101.6×5 of steel S355J2. The rigid HGV weighing 10.10 tons collided against the parapet at 73 km/h impact speed and 15.8º angle (Figs. 4.5 and 4.6). After the front right-hand side of the vehicle crashed into the parapet, the vehicle changed its direction of travel, and the rear end of the vehicle collided heavily against the vehicle parapet. The vehicle separated from the parapet after being in contact with it for a distance of 10.3 m. While the rear end was bouncing, the vehicle nose turned against the vehicle restraint system again and the vehicle drove slightly over the terminal of the system.

Figure 4.5 Impact sequence, view from the front (Courtesy of HUT).

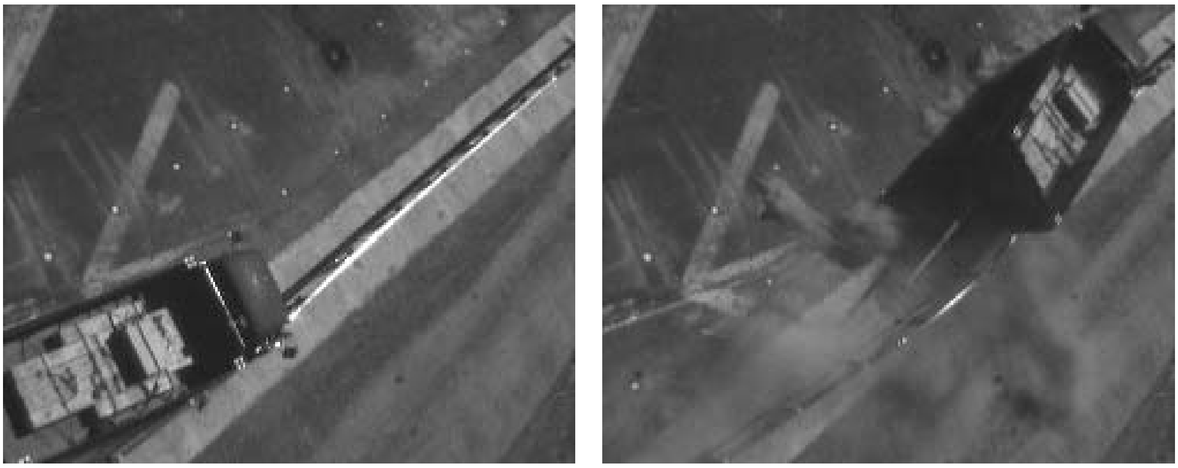

Figure 4.6 Impact sequence, view from above (Courtesy of HUT).

Figure 4.7 Deformation of the vehicle parapet after the impact and the functioning of the deformation element (Courtesy of HUT).

Three posts next to each other broke off from the base plates, and the same joints of two posts near them were partly broken (Fig. 4.7). Maximum dynamic lateral displacement of the vehicle parapet was 95 cm. The corresponding static value was 75 cm, while the static collapsing displacements of the deformation elements were at a maximum 10 mm. The working width of the system was 1.30 m. The HGV was not in running condition after the test.

Test 3 (TB 11)

A car weighing 902 kg collided against the modified High vehicle parapet, similar to the one in Test 2, at 104 km/h impact speed and 20º angle (Fig. 4.8). The impact point was 0.8 m before the post. The front right-hand side of the vehicle collided heavily against the second post after the impact point, and the right front wheel, the radiator grille, the bonnet and the windscreen became detached. The car bounced off the parapet after being in contact with it for a distance of 4.1 m and changed its direction of travel to the left away from the vehicle parapet. After the impact the car was no longer in running condition (Fig. 4.8).

The maximum dynamic lateral displacement of the vehicle parapet was 12 cm. The corresponding static value was 8 cm, while the deformation elements collapsed 10 mm at the maximum (Fig. 4.9). PHD and ASI (Fig. 4.10) values of the impact severity assessment indices conformed to the requirements of the standard, but the THIV value was over the maximum of 33 km/h.

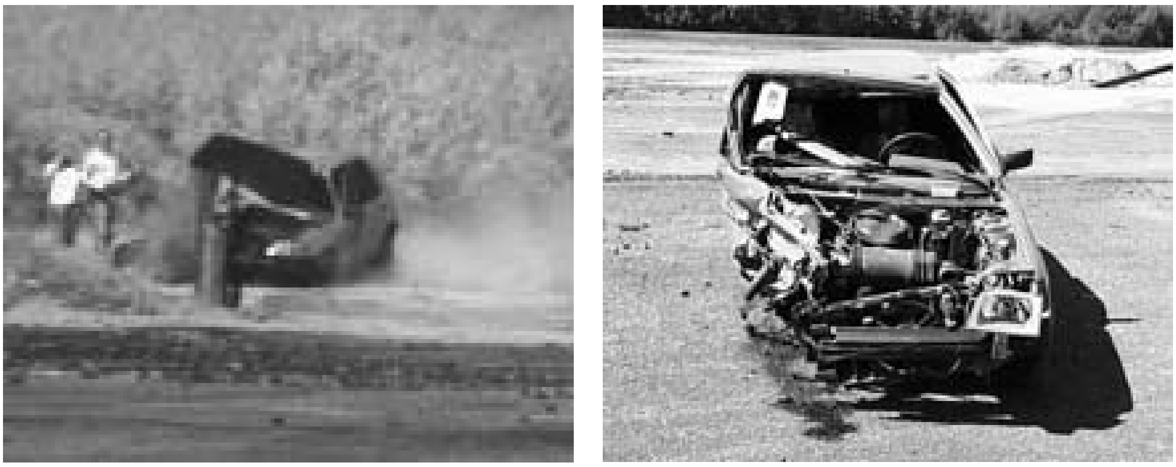

Figure 4.8 The impact and damages to the test vehicle (Courtesy of HUT).

Figure 4.9 Deformation of the vehicle parapet after the impact and the functioning of the deformation element (Courtesy of HUT).

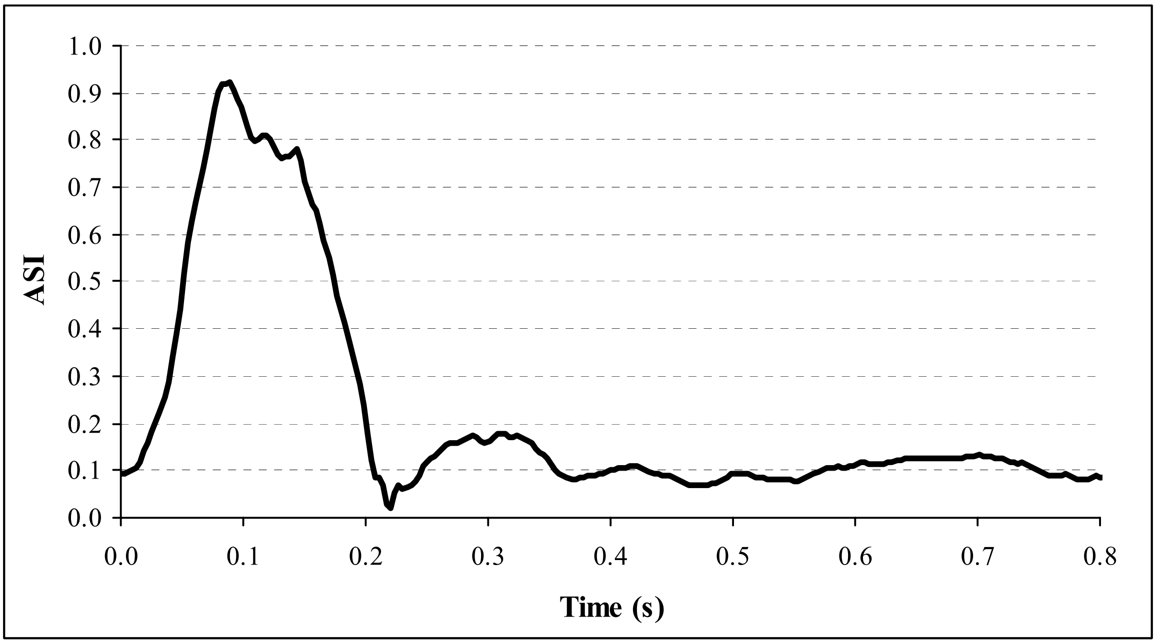

Figure 4.10 The acceleration severity index (ASI) value computed as a function of time.

Impact severity assessment indices computed from the test result were:

- ASI = 0.92
- THIV = 37 km/h
- PHD = 8.0 g

Conclusions

The High vehicle parapet, the present standard vehicle parapet of Finnra, did not have enough capacity to resist a heavy vehicle collision of containment level H3. It met the requirements of level H1 in the heavy vehicle collision, when equipped with pipe deformation elements. On the other hand, the vehicle parapet was slightly too rigid in the light vehicle impact. The computed value of theoretical head impact velocity, one of the vehicle occupant impact severity assessment indices, was exceeded.

It was estimated that the tested modified High vehicle parapet would fulfil the requirements of the light vehicle test if the collapsing force of the deformation element would be lower, and thus more energy would be absorbed. A small reduction was estimated not to decrease the strength of the parapet in the heavy vehicle collision. On the contrary, by absorbing more impact energy, the deformation elements were expected to lower the stresses on the posts, which was found to be quite critical in the heavy vehicle collisions where several posts were broken. A suitable reduction was defined as 20…25 per cent by comparing the squares of the measured and required values of THIV (energy changes as square of velocity). Thus it was decided to reduce the wall thickness of the pipe deformation element from five to four millimetres, but no new test was arranged to verify the change.

Although the modified present standard vehicle parapet was estimated to conform to containment level H1 after a small reduction in the collapsing force of the deformation elements, the project, described in this thesis, was launched to develop new standard vehicle parapets. The development work began, because the tested modified High vehicle parapet with pipe deformation elements was considered too wide a construction of a too low containment level.

4.2.2 Swedish standard vehicle parapet

Introduction

The impact tests that verified the containment level H2 of the Swedish standard vehicle parapet were conducted in November 1997 in Munich-Allach, Germany. The testing laboratory was the Bundesanstalt für Straßenwesen (BASt) and the client the Transport Research Institute (VTI). The tests were carried out on the basis of draft European Standards prEN 1317-1 and 1317-2 as of January 1996. The results and pictures presented here are from the test reports edited by Ellmers et al. (1998).

Test arrangements

The posts of the parapet were grouted into the holes of a concrete foundation beam representing the high edge beam of a bridge. The beam was 0.45 m in width, 0.90 m deep and about 45.00 m in length. The length of the vehicle parapet of the vehicle restraint system was 46.80 m. Its front edge was on average 0.10 m above the surface of the asphalt roadway. The test vehicles, an Opel Corsa car and a MAN SL 200 bus, are presented in Figure 4.11. With the bus was used a ballast of 3.39 tons distributed over the interior of the vehicle.

The ECV (Electronically Controlled Vehicle) system provided by TÜV Süddeutschland (Technical Inspection Authority) was used to achieve controlled movement of the test vehicles. The vehicles were accelerated by the power of their own engines. During the acceleration phase the vehicles were guided and kept in the selected lanes by a current-carrying cable laid in the roadway. Shortly before the impact points the vehicles were disconnected from the ECV system (steering, clutch) so that the vehicles travelled freely (i.e. without the influence of an outside force) into the tested vehicle parapet. At the end of the tests the vehicles were slowed down by remote control.

Figure 4.11 Test vehicles at the impact points before the impact tests.

Car test (TB 11)

A car weighing 878 kg collided against the vehicle parapet at 101.3 km/h impact speed and 20.0º angle (Fig. 4.12). The impact point was 0.88 m before the post, which was at about the midpoint of the rail between two posts (post spacing 1.8 m). After the impact the car changed its direction of travel and separated from the vehicle parapet after being in contact with it for a distance of 3.2 m. The maximum static lateral displacement of the vehicle parapet was 8.0 cm (Fig. 4.13). The impact severity assessment indices conformed to the requirements of the standard, although the acceleration severity index reached the maximum allowable value (Fig. 4.14):

- ASI ≈ 1.4
- THIV = 30 km/h
- PHD = 4.2 g

After the impact the car was no longer in running condition (Fig. 4.13). The complete wheel suspension of the left wheel including the front pillar of the left-hand side was displaced (backwards) to the right-hand side. During the impact the left hand side panel and part of the front left footwell were strongly deformed and penetrated into the compartment.

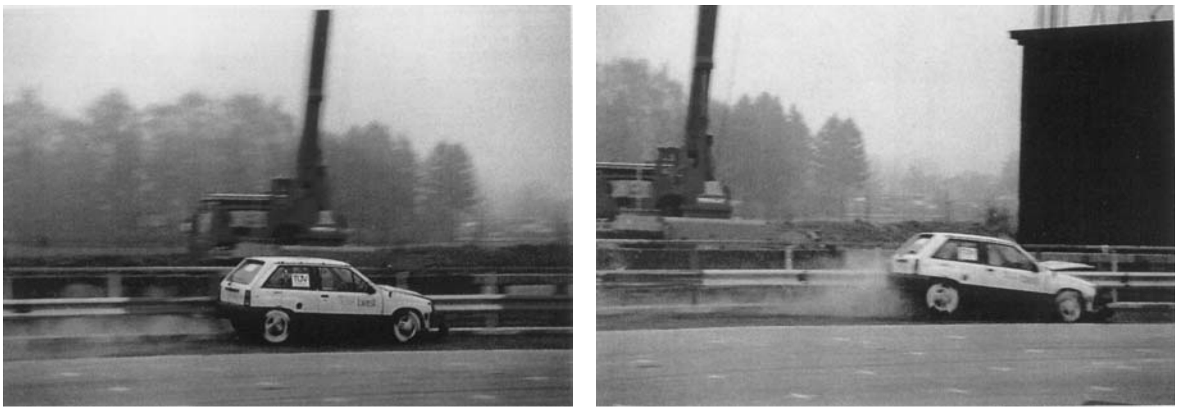

Figure 4.12 Impact sequence.

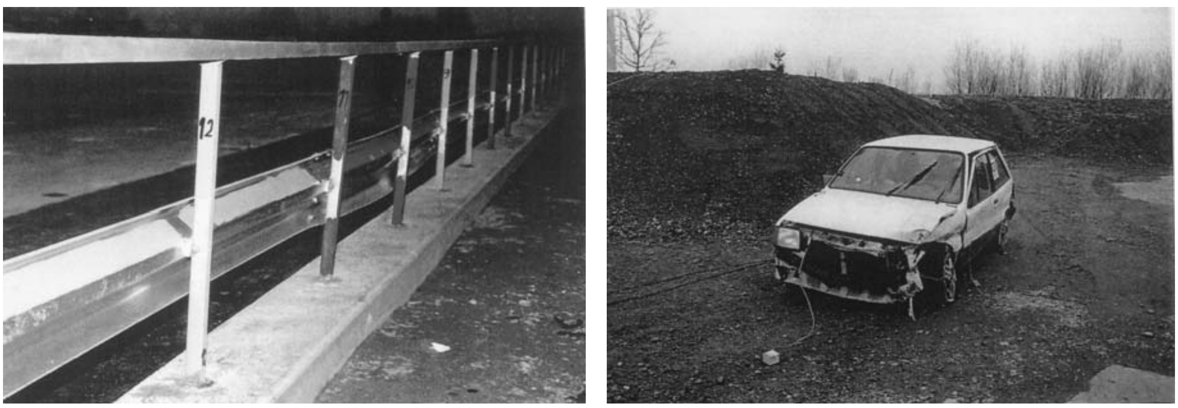

Figure 4.13 Impact damages to the vehicle parapet and the test vehicle.

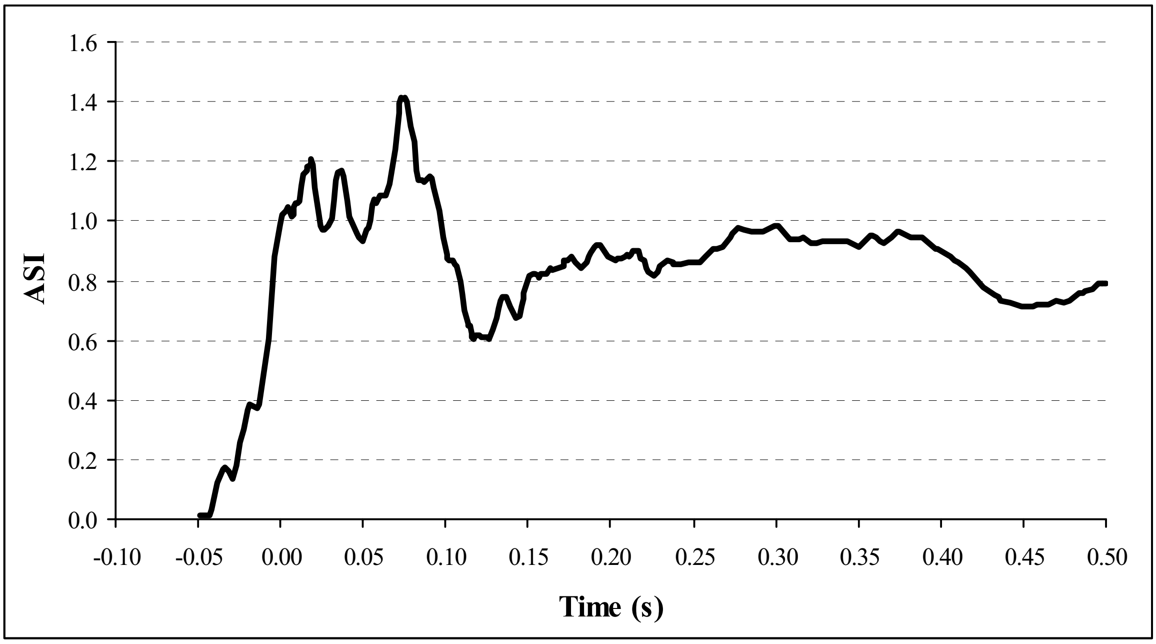

Figure 4.14 The acceleration severity index (ASI) value computed as a function of time.

Bus test (TB 51)

A bus weighing 12.69 tons collided against the vehicle parapet at 71.5 km/h impact speed and 20.8º angle (Figs. 4.15 and 4.16). After the front left-hand side of the bus crashed into the system, the bus changed its direction of travel and the front wheels lifted off the ground. The change of direction occurred over such a short distance that in the further course of the test the rear end of the bus collided heavily against the vehicle parapet and tilted. The rear right-hand wheel lost contact with ground and in the further course the whole rear end of the bus rose. After being in contact with the vehicle parapet for a distance of approximately nine metres, the bus separated from it, continued forwards in a series of pitching and rolling movements and finally came to a standstill. The bus was not in running condition after the test.

The maximum dynamic lateral displacement of the system in the impact of the front end of the vehicle was 50 cm (upper edge of vehicle parapet) and in the impact of the rear end of the vehicle 83 cm (upper edge of bus). The static lateral displacement of the vehicle parapet was 74 cm (Fig. 4.17). The rail deformed greatly, got squashed against the posts and partly cracked. The working width of the vehicle parapet was graded as W3 (W ≤ 1.0 m).

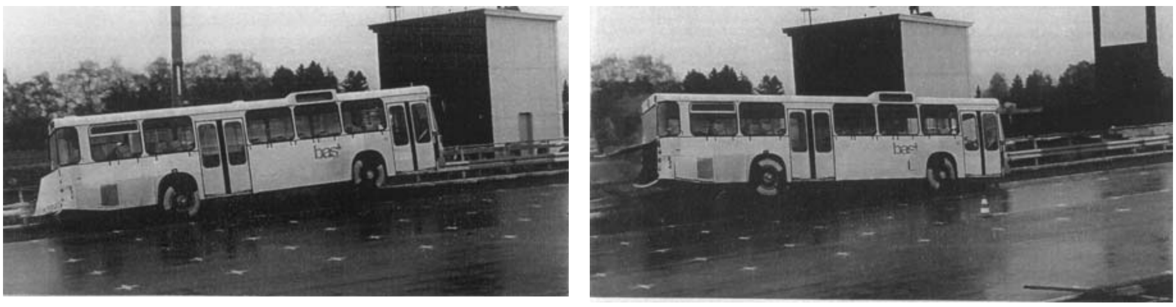

Figure 4.15 Impact sequence, view from the side.

Figure 4.16 Impact sequence, view from the front.

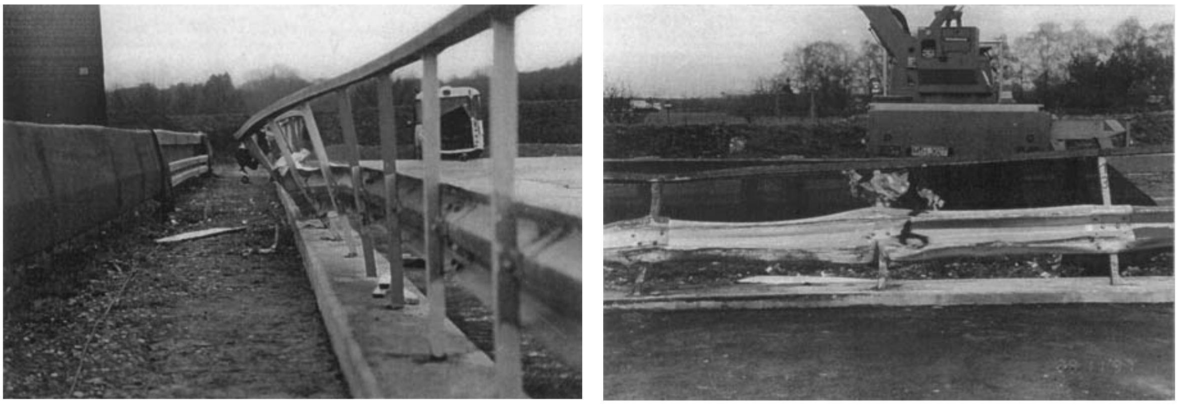

Figure 4.17 Deformation of the vehicle parapet after the impact. The cracking of the rail can be seen in picture on the right.

4.3 Introduction of Nordic impact simulation project

FORCE Technology (at the time Safetec Nordic) was contracted by the Swedish National Road Administration in summer 1999 to develop finite element models of vehicles for crash analyses against vehicle restraint systems according to Standard EN 1317. Later in the spring of 2000 the Norwegian Public Roads Administration complemented the project with simulation cases. The Finnish vehicle parapet was tested with the application for the first time in spring 2003. The development project of the Nordic simulation application was initiated in order to (Sangø et al. 2001):

- Investigate the possibility to establish a replacement for full-scale tests when the vehicle restraint system is subjected to minor modifications
- Minimise the cost related to testing of new vehicle restraint systems:
    - pre-simulations can reveal weak points in design
    - pre-studies leading to full-scale testing
- Simulate existing vehicle restraint systems:
    - will they meet the requirements of the standard
- Be able to respond quickly to consequences of design changes
- Establish the possibility for parameter studies
- Establish a flexible procedure to investigate other test scenarios than tests according to Standard EN 1317
- Reduce the cost of testing in general and increase tests' reliability concerning traffic safety

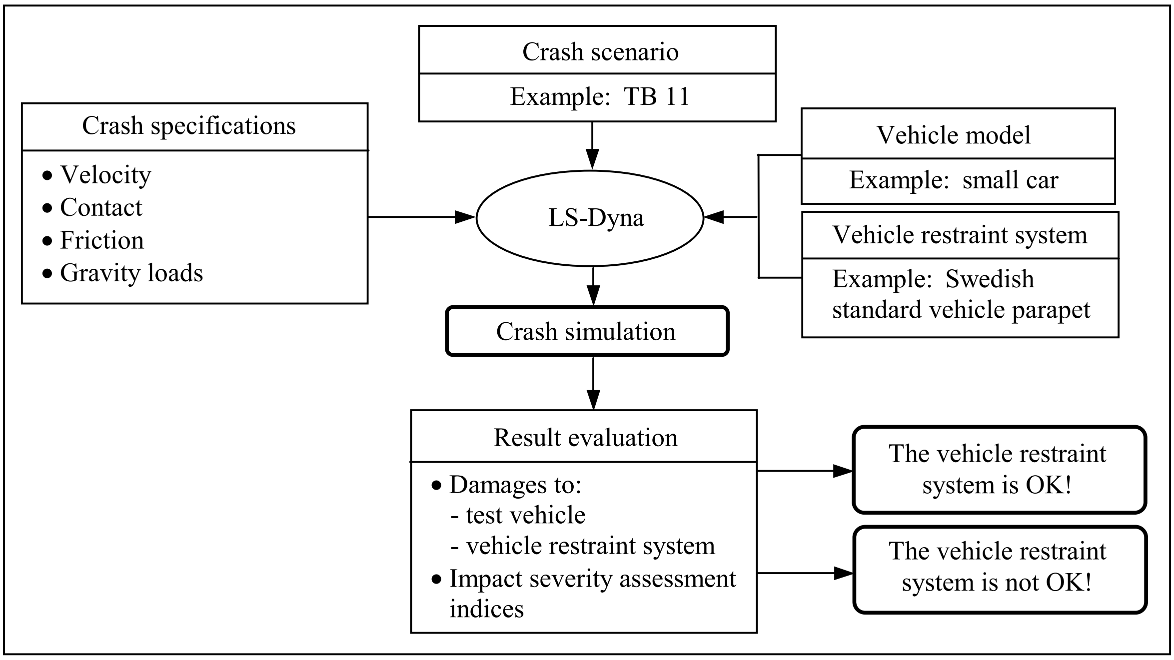

Figure 4.18 Procedure for crash simulations (Sangø 2001).

The basis for model development were vehicle models received from the National Crash Analysis Center (NCAC) and Scania and modified for the project. The following vehicle models were developed:

• Small car	900 kg
• Large car	1 500 kg
• Bus	13 000 kg
• Rigid HGV	16 000 kg
• Articulated HGV	38 000 kg
• Rigid HGV with trailer	60 000 kg

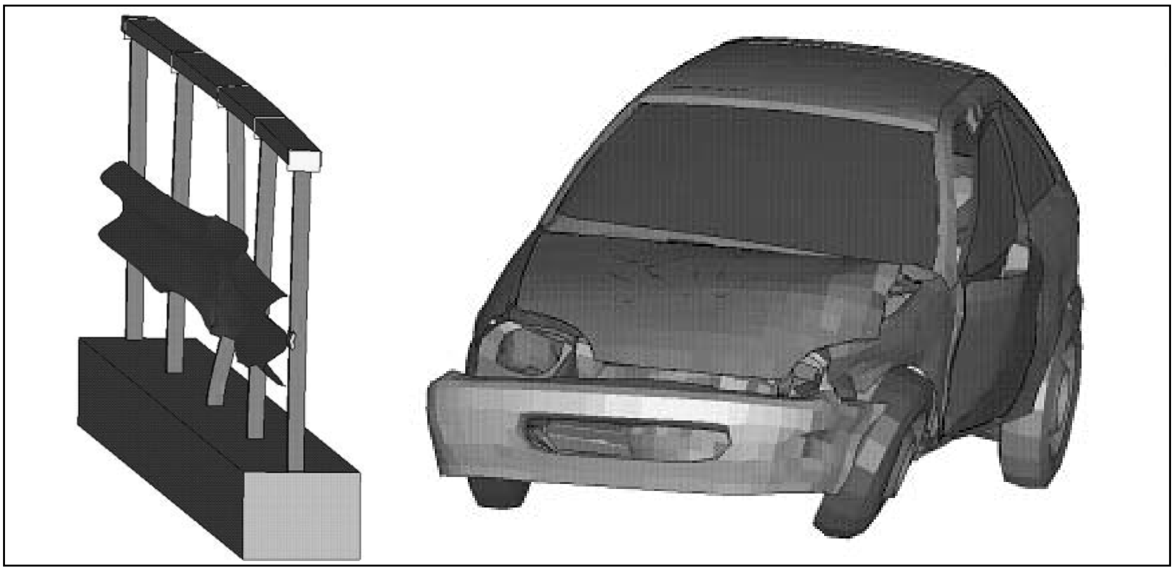

Figure 4.19 Impact damages to the Swedish standard vehicle parapet and the car (GeoMetro) causing them according to the computer simulation of Test TB 11 (compare with Fig. 4.13). (Sangø 2001)

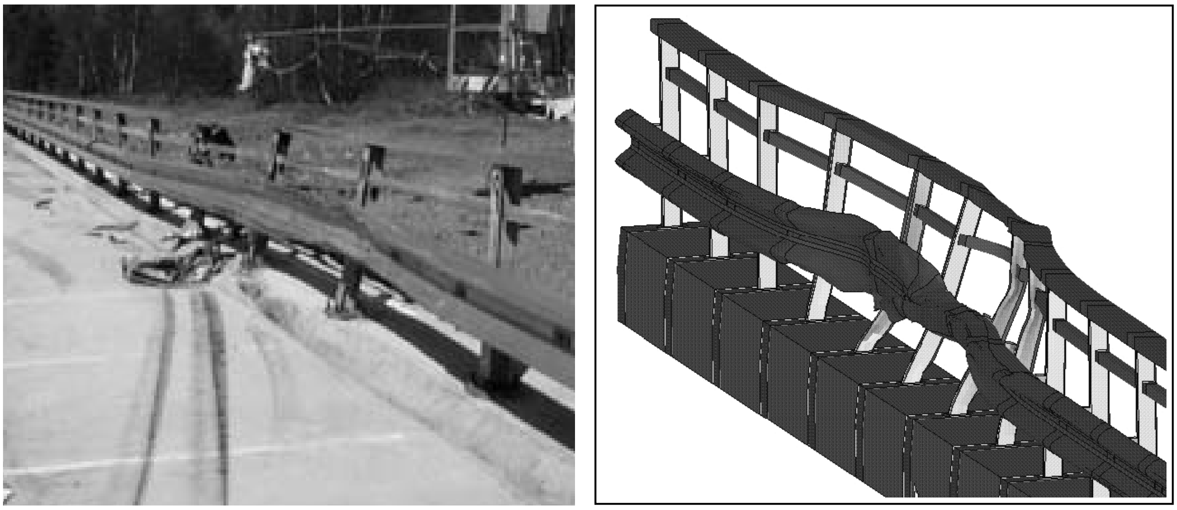

Figure 4.20 Impact damages to the Norwegian standard vehicle parapet in the full-scale and simulated Test TB 51 with a bus (Sangø 2001).

In order to perform analytical crash tests on a vehicle restraint system, dynamic nonlinear finite element analyses were performed (Fig. 4.18). Finite element models of vehicles and vehicle restraint systems without expansion joints were prepared in LS-Dyna format. LS-Dyna is a special purpose finite element analysis program used widely for car-crash simulations and by the defence industry.

The reality accuracy of the developed system was verified by comparing the computed benchmark simulations of the Swedish standard vehicle parapet to full-scale tests (Fig. 4.19). Benchmark simulations were later done also on the full-scale tests of Norwegian safety barriers on bridges (Fig. 4.20) and roads. The results from these benchmark simulations corresponded reasonable well with the full-scale tests.

Later the application has been used, for instance, on the Swedish standard vehicle parapet to analyse the effects of the low edge beam and the Kohlswa rail (Swedish National Road Administration 2002a), which has about four times lower bending stiffness and two times lower elastic moment about the vertical direction than the W rail. According to the analyses, the occupant impact severity is too high if the vehicle parapet is installed on the low edge beam.

In the case of the Kohlswa rail, the computed occupant impact severity was low enough if the parapet is on a high edge beam and the impact angle is 18° at the maximum. This leads to a situation where the effective width of the bridge cannot be more than seven metres. Instead of limiting effective width, according to the analyses, the Kohlswa rail can be equipped with deformation elements to make it work properly in a light vehicle impact.

The simulation application was tested also in the development of the new Finnish standard vehicle parapets. Simulations were made of a structure subjected to several full-scale impact tests which thus created a good benchmark for the simulations. The results of the simulations and full-scale impact tests are presented in Chapters 5.3.2…3.

5 EMPIRICAL STUDY

5.1 Description of the analysis method

5.1.1 Overview

The analysis method used to develop the new Finnish standard vehicle parapet types was a combination of calculation analyses, full-scale impact tests and experiences gained from the process. FE analyses were simplified to keep the computing time and expenses reasonable and to minimise the factors of uncertainty. All impact analyses were done in the accident design situation without partial factors for accident actions and partial safety factors for resistances.

FE analyses were made with LUSAS Bridge Plus Versions 13.2…13.4, the bridge analysis system of a widely used three-dimensional finite element program. The Plus Version of the program has additional solver capabilities, nonlinear and dynamic, among other things. The LUSAS finite element system involves three stages: pre-processing, finite element solving and results-processing.

5.1.2 General information about the FEM

The finite element method used for structural analyses can be static or dynamic analyses based in linear or nonlinear calculations (Fig. 5.1). Dynamic and nonlinear analyses are computationally more expensive than static and linear ones.

If loadings may not be considered static, or if general inertia and damping (the property that causes dissipation of energy in a system) effects are significant, the transient dynamic analysis must be applied. It requires discrete study of displacements, velocities and accelerations in both the spatial and time domains. The spatial solution is progressed through time in a step-by-step manner assuming an interpolation through a small time increment or time step. For known initial or starting conditions successive progression through the time domain yields the transient response of the structure. A nonlinear analysis is required for problems where the load-deflection response is not linear. Three common sources of nonlinearity are (Finite Element Analysis Ltd. 1999):

- Geometric nonlinearity
- Material nonlinearity
- Boundary condition nonlinearity

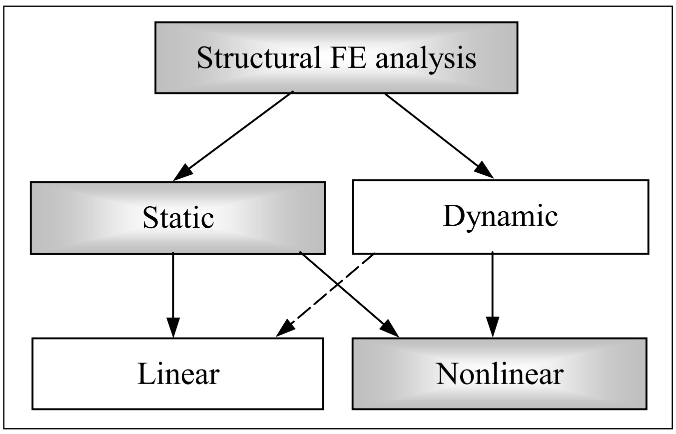

Figure 5.1 Overview of structural finite element analysis. The main method of this study is shown in grey.

All real situations are to a certain extent nonlinear, but the need for nonlinear analysis depends on the structural significance of these factors. In many cases the assumption of linearity is justified. In nonlinear analysis it is not possible to directly obtain an internal stress distribution which is in equilibrium with the applied loadings. A change in stiffness due to nonlinear effects will result in an out-of-balance vector. The object of nonlinear analysis is, therefore, to calculate a situation of static equilibrium by eliminating the out-of-balance vector.

Geometric nonlinearities arise from significant changes in structural configuration and are often associated with large deflections, large rotations and/or large strains. In geometrically nonlinear analysis the current state of displacement is continually monitored and the stiffness of the structure updated as a function of displacement change.

Material nonlinear effects arise from a nonlinear constitutive relationship (i.e. the relationship between stress and strain) and are associated with progressive material degradation. A common example of material nonlinearity is the elasto-plastic yielding of metals. The material response is assumed to be initially linear where stress increases in direct proportion to strain, until a yield point. After that, the value of stress changes in different proportion or is constant while the strain increases. Degradation of the material reduces the stiffness of the structure and hence induces nonlinearity.

Boundary condition nonlinearities (deformation dependent) arise from modifications to the restraints during analysis: modified support conditions during loading or a contact (e.g. collision of the vehicle) with another structure or another part of the same structure. In order to monitor the onset and effects of boundary condition nonlinearity, the current state of displacement must be monitored.

5.1.3 Used finite element analyses

Introduction

The static nonlinear finite element analyses presented here (Fig. 5.1) were made to estimate the capacity of the developed vehicle parapet against heavy vehicle collision and to understand the functioning of single structural components. The first one was done by the complete analysis method including a model of the whole vehicle restraint system loaded with a force defined from the FE analyses of previous full-scale impact tests. Results from the FE analyses of single components, like deformation elements, were used together with the experiences from previous tests to estimate the functioning of the vehicle parapet in the new impact tests.

The used FE analyses involved nonlinear 3D beam and shell elements and took into account geometric and material nonlinearities. In the analyses of single components boundary condition nonlinearity was also taken into account with the modelling of the concrete grouting under the base plate. Geometric nonlinearity was computed by using the Co-rotational formulation for beams and Total Lagrangian for shells. Both formulations are valid for arbitrary large displacements. Material nonlinearity was achieved by modelling elasto-plastic yielding of steel components, so that stress increased in direct proportion to strain, until it reached yield value after which it was constant.

The values of the impact severity assessment indices could not be analysed based on the computed data. Their analysing would have required a much more complicated model of the vehicle parapet and load. The load should have been the object hitting the parapet with known deformation and energy absorbing properties, which would have required dynamic analysis with the geometric, material and boundary condition nonlinearities — as in the case of the Nordic simulation application which was tested as part of the Finnish vehicle parapet development described in this thesis.

Complete analysis method

The computer simulation used for estimating the maximum level of containment of the developed Finnra H2 vehicle parapets involved a simplified finite element method. The model consisted of nonlinear 3D beam elements, and the loading was a static force equal to the dynamic vehicle impact (Fig. 5.2). Modelling and analysis of the previous full-scale heavy vehicle impact tests was needed to determine static loading (Fig. 5.3).

The loading was assumed to be a lateral knife-edge load, perpendicular to the vehicle parapet affecting the rail and handrail, with a length multiple of the post spacing of the parapet. Length division was estimated to be accurate enough, because the main function of the rails, based on the analyses of the whole structure, was to transfer the loading to the posts. The length of the static load and its proportional distribution between the rail and handrail were determined by testing different variations and comparing the computed deflections with the measured dynamic deflections of the full-scale impact tests.

Because of the similarities of the developed parapet and the standard vehicle parapet of SNRA, both aesthetically light but ductile structures, the loading could be defined precisely enough by analysing the bus test on the Swedish standard vehicle parapet. The proportional distribution of the load between the rail and the handrail was, however, difficult to estimate, because the posts did not break in the impact test and thus the differences in deformations caused by different loading variations were quite small.

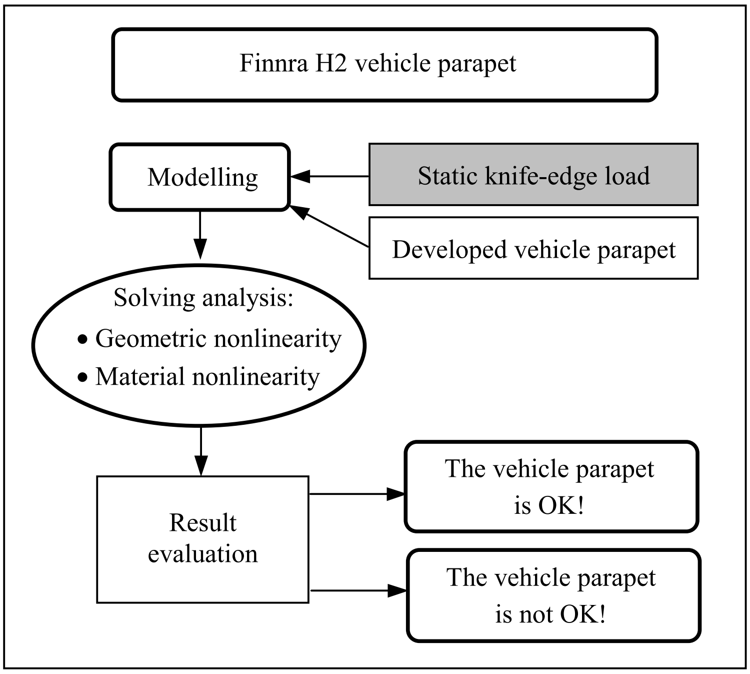

Figure 5.2 Procedure for heavy vehicle crash simulation of the Finnra H2 vehicle parapet.

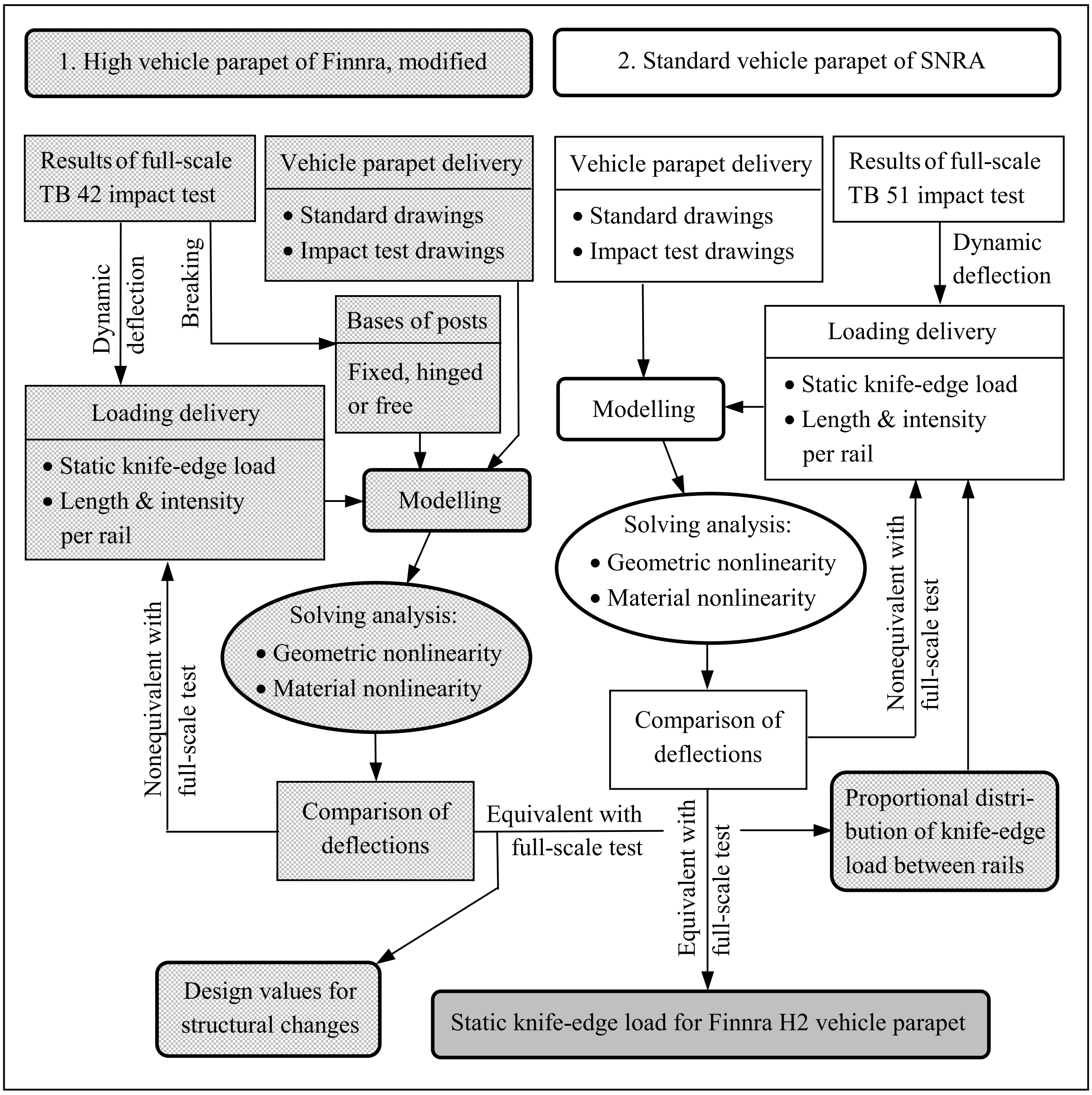

Figure 5.3 Analysis of the heavy vehicle load for the Finnra H2 vehicle parapet and design values of the Finnra H1 vehicle parapet.

To help solve the distribution problem, a level H1 heavy vehicle collision against the present Finnish standard vehicle parapet, the High vehicle parapet of Finnra, was analysed. At the same time, the design values of the Finnra H1 vehicle parapet for structural changes were also received. Because the welded joints between the posts and base plates of the present standard vehicle parapet did not yield much before fracture, the bases of the posts were modelled to correspond to the final situation of the impact-tested structure. Joints were defined to be fixed (unbroken), hinged (fractured) or free (broken-off).

Analyses of single structural components

Nonlinear FE analyses of structural components were made to check the structural capacity of a single component and to estimate the effect of the component on the functioning of the whole vehicle parapet. The main effort was put into the development of suitable deformation elements. Results of deformation elements analyses were used together with the experiences from previous TB11 car tests to estimate the impact severity of the vehicle parapet in the new light vehicle tests.

The nonlinear 3D shell element models of the single deformation elements were made to compute the collapsing force of the components. The stretches of the developed and already tested vehicle parapets were also modelled to observe the functioning of whole parapet structures equipped with deformation elements. The vehicle parapets were modelled by using nonlinear 3D beam elements as the frame of the parapets and nonlinear 3D joint elements as deformation elements.

Another example of the analyses of single structural components are the calculations on the base plate of the Finnra H2 vehicle parapet. In the beginning the posts of the vehicle parapet were grouted into the bored holes of the concrete foundation slab in the full-scale impact tests. Later bolt fixing was used, which was analysed by the nonlinear 3D shell elements.

5.1.4 Arranged full-scale impact tests

Introduction

Nine new impact tests on vehicle parapets have been arranged according to Standard EN 1317 at the airfield in Pori, Finland in 2000-2003 (Table 5.1). Seven of these involved cars while two involved buses. The Laboratory of Highway Engineering at HUT has been the testing laboratory. Tests have been made to verify whether the developed structures conform to the European standard. When satisfactory impact performance has not been achieved, the results of the tests have been used in the development of structures for new tests.

The first one to be tested was the new developed Finnra H2 vehicle parapet with the 2-pipe rail. Impact tests were arranged with both light and heavy vehicles. Later, several car tests and one bus test on the Finnra H2 vehicle parapet were run. In these tests the parapet was equipped with the uniform open section rail, similar to the rail of the present standard vehicle parapet, instead of the 2-pipe rail.

The Finnra H1 vehicle parapets are modifications of the High vehicle parapet. In their development the impact tests on the High vehicle parapet were utilised, which is why no new heavy vehicle test was arranged. Only car tests were arranged to verify the adequately low risk of vehicle occupant injuries, if the 2-pipe rail, similar to the rail of the Finnra H2 vehicle parapet, is used instead of the uniform open section rail.

Table 5.1 Impact tests on the new Finnish standard vehicle parapets.

Test n:o	Tested parapet	Test date	Acceptance test
4	Finnra H2 vehicle parapet, 2-pipe rail	06.06.00	TB 11
5	Finnra H2 vehicle parapet, 2-pipe rail	20.06.00	TB 51
6	Finnra H1 vehicle parapet, 2-pipe rail, ver. 1	12.09.00	TB 11
7	Finnra H1 vehicle parapet, 2-pipe rail, ver. 2	26.09.01	TB 11
8	Finnra H2 vehicle parapet, 240/6 rail, ver. 1	16.07.02	TB 11
9	Finnra H2 vehicle parapet, 240/6 rail, ver. 2	08.08.02	TB 11
10	Finnra H2 vehicle parapet, 240/6 rail, ver. 3	28.08.02	TB 11
11	Finnra H2 vehicle parapet, 240/6 rail, ver. 4	04.09.02	TB 51
12	Finnra H2 vehicle parapet, 240/6 rail, ver. 4	28.08.03	TB 11

The results of the impact tests presented in Chapters 5.2…5.4 are based on test reports edited by Valtonen & Laakso (2000, 2001 and 2003). The impact moment photos are still frames of videos or series of high speed camera photos. Freeze points in each separate case were selected for this thesis so that the pictures visualise the nature and severity of the collision as well as possible.

Test arrangements

The impact test arrangements were similar to the previous tests described in Chapter 4.2.1. A kind of validation of the arrangements and results of the tests made by HUT has been provided by common European calibration tests, where the measured and computed results of different testing laboratories were compared after each laboratory had driven a similar new car against a similar concrete wall safety barrier and analysed the impact. A similar test is also going to be done using the test cars that each laboratory normally uses. The tests with new cars were organised in 2002 and 2003.

The vehicle restraint systems were manufactured and installed by TTP-Yhtiöt Oy. Excavation and concrete work was done by the Finnish Road Enterprise. The total length of the tested vehicle restraint systems was 64 m including a 28 m vehicle parapet and 18 m end treatments on both ends of the structure. The length of the vehicle parapets and the transitions of the end treatments, where the handrail was anchored to the rail, were similar to the previous tests. The terminal parts of the end treatments, where the rail was anchored to the ground, were lengthened from the previous 4 m to 12 m to meet present requirements.

The posts of the vehicle parapet were anchored to the same concrete foundation slab as in the previous tests. In the tests on the Finnra H2 vehicle parapets the posts were fixed to a 0.10 m high and 0.45 m wide concrete beam anchored to the foundation slab, which represented the high edge beam of the bridge. High edge beams have also been used, for instance, in the testing of the Swedish and the Norwegian standard vehicle parapets. The high edge beam was used because the low edge beam is nowadays rarely used on bridges. The low edge beam was nevertheless used in the tests on the Finnra H1 vehicle parapet to make the new tests compatible with the previous ones.

Two types of fixing to the edge beam were tested with the Finnra H2 vehicle parapets: installation of the posts into bored holes, which were later grouted, and bolt fixing with base plates. With the Finnra H1 vehicle parapets fixing was done by bolts as earlier.

The inspected and roadworthy test vehicles were a Peugeot 205 car and Scania Delta 200A (Test 5) and Scania 116 (Test 11) buses. The water tanks (1.60 tons in Test 5 and 0.96 tons in Test 11) belted onto the seats were used inside the buses as ballast to reach the total mass requirement of the test vehicles. The pulling (car tests) and pushing (bus tests) of the test vehicles was done by an HGV as in the previous tests (see Fig. 4.1). The speed of the vehicles was first measured by radar gun in situ and later verified by analysing high speed camera photos.

5.2 Finnra H2 vehicle parapet with 2-pipe rail

5.2.1 Developed structure

The new, containment level H2, Finnish standard vehicle parapet (Fig. 5.4) is hot galvanised and reaches 1.2 m above the road surface. When equipped with a 2-pipe rail and used on a high edge beam, it weighs about 47 kg/m (expansion joints included) and is about 40 per cent more expensive than the present Finnish standard vehicle parapet. It is also 0.1 m higher than the present standard structure. The raising of the parapet is based on an analysis of bicyclist accidents on bridges in Finland, comparison of existent European parapets and conversations with the product development departments of Finnish bicycle manufacturers.

The parapet consists of posts with a spacing of 2.0 m, a 2-pipe rail and cold-rolled U-profile as handrail. Instead of the 2-pipe rail, a uniform open section rail can also be used as in the present standard vehicle parapet but with the lower rail (see Chapter 5.3.1). The lower rail is used also with a 2-pipe rail if the parapet is on a low edge beam. The rail normally used with the Finnra H2 vehicle parapet is the 2-pipe structure because of aesthetic and openness requirements. The centre line of the posts is at the same distance from the inner edge of the edge beam as with the present standard vehicle parapet, and the width of the construction is such that the effective width of the bridge goes as much above the edge beam as earlier.

The rail and handrail of the Finnra H2 vehicle parapet have installation and expansion joints (± 5 mm) at intervals of 12 m. Expansion joints with bigger free motion are used above the expansion joints of the bridge. Joints of the handrail that have normally been welded in situ are now bolted, as has already been the case with the rail, which improves durability. The diagonal anchoring of the handrail to the edge beam of the bridge, used when the free motion of the expansion joint is over ± 50 mm, is a new structural component developed for use in Finland. It transmits a force from the handrail into the edge beam on both sides of the expansion joint, so that the force does not have to go through the expansion joint of the handrail with a big gap, which would reduce too much the structural capacity of the parapet.

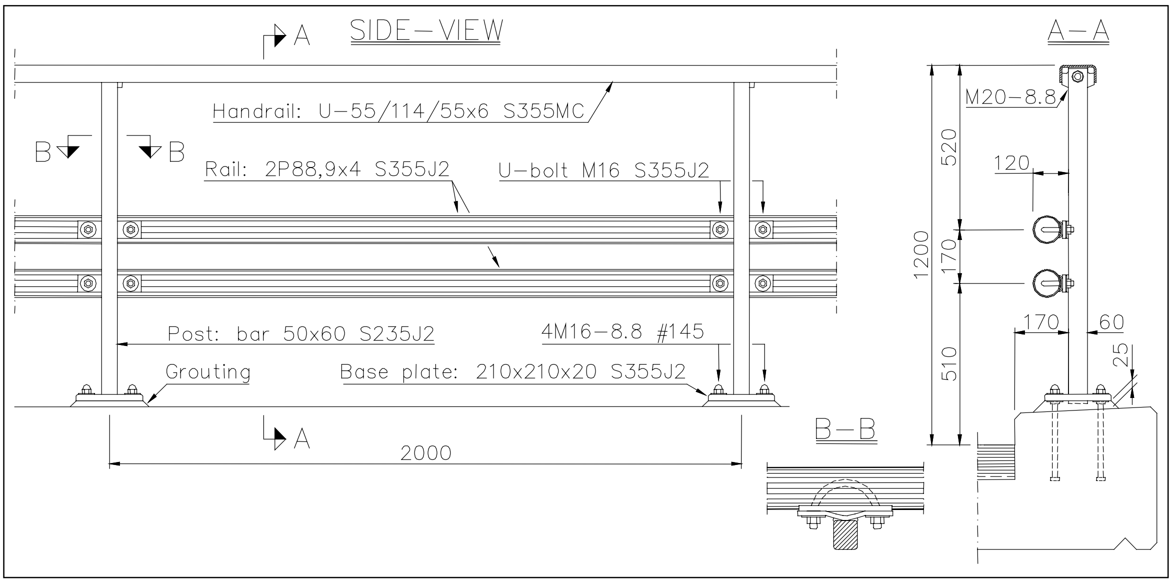

Figure 5.4 General drawing of the Finnra H2 vehicle parapet with 2-pipe rail.

Requirements for narrow and open construction have led to thin but ductile solid steel bar posts. The post spacing is the same as with the present structure. It is a round figure, which can thus easily be used also to estimate the length of an existing bridge. The posts have relatively low bending stiffness and yield value of bending moment while the used 2-pipe rail is quite rigid. The rail has enough capacity to prevent a severe collision against the post and the bending of the post dampens the impact. Thus it provides an adequate occupant impact severity level without big deformation elements with the rail.

The posts are anchored to the bridge deck by bolts. Its appearance has been improved by using capnuts above the base plate. Grouting of the posts into the holes of the edge beam is also possible, but so far it has only been used in the experimental building projects. The developed hole fixing system for the posts does not involve as severe a durability problem as the similar detail of the present standard vehicle parapet due to smaller holes, the solid cross-section of the posts and the extra protective paint between the posts and the concrete. Thus, its usage may increase in the future.

The pipe profiles are closed, because open tubular sections, as in Figure 3.4, can get dirty inside which weakens them corrosion resistance. They may also be more easily damaged by impact and may open a little (cross-section reshaped) when being cold-bent to fit the curvature of the road. The last reason has limited the development of the joint between the 2-pipe rail and the posts. Connection pieces cannot be attached to the pipes before cold-bending them by rolling, which is normally done in situ.

The handrail is a new cold-rolled U-profile (Rautaruukki Oyj). Traditionally, the handrail has been an acute-angled hot-rolled profile. The cold-rolled profile was chosen as the handrail because it gives an aesthetically more finished appearance to the parapet and is also better alternative if desired to paint, as it is a round-angled and has a smoother surface.

5.2.2 Calculation analyses

Overview

Analyses of single structural members of the developed vehicle parapet frame were done by comparing the cross-section properties of the members to the corresponding values of earlier impact-tested vehicle parapets. The functioning of the whole vehicle restraint system under a heavy vehicle impact was then analysed by using the complete FEM analysis method. In the first stage, it was used with preliminary structural members to analyse the adequate vehicle parapet length and the height of the edge beam to be used in the full-scale impact tests. Later, it was used as a tool to estimate made structural member choices.

Posts

The moment of inertia and the elastic moment capacity of the different post alternatives are presented in Table 5.2. The plastic moment capacity of rectangular bars, which is an important property of posts designed to have a plastic hinge at the root for the impact, is 20 per cent higher than the elastic one according to Finnish codes. The first heavy vehicle FEM analyses were made using the same 55×55 bar posts as with the impact-tested Swedish standard vehicle parapet. The capacity of 55×55 bar was, however, too low, because the post spacing is 2.0 m instead of the 1.8 m used in Sweden.

Table 5.2 The moment of inertia (I) and the elastic moment capacity (M_u) about the longitudinal direction of parapet of different rectangular bar post alternatives.

Cross-section Steel	55×55 S235JR	50×60 S235J2	40×60 S355J2
I (cm^4)	77	90	72
M_u (kNm)	6.5	7.1	8.5

Two different alternatives were designed for the post of the Finnra H2 vehicle parapet: a 50×60 post and 40×60 post of higher strength steel. Although the latter was at the time more easily available, the 50×60 bar was chosen. Its bending properties are just about as much better as the post spacing in Finland is bigger than in Sweden. It is also notable that its moment of inertia about transverse to the longitudinal direction of the parapet is two times higher than with the 40×60 bar, and thus it was estimated to work better in the longitudinal direction of the parapet as a lateral support of a handrail having high tensile force.

The chosen post corresponded to the one successfully used with the Swedish standard vehicle parapet. Thus it was expected to work in a similar way: bend adequately in case of a light vehicle impact, but be ductile enough and not break in a heavy vehicle collision, while having enough strength to withstand small impacts, snow clearance, etc. without notable damages.

Rail

The rail was first designed as a uniform open section similar to the currently used 230/5 rail. Developed variations of the open section rail (240/5, 230/6 and 240/6) are presented in Chapter 5.3.2. The 2-pipe rail was later selected to be use as a rule and was thus impact-tested before the open section rail. Heavy vehicle FEM analyses with the open section rail were not made again because the changing of the rail was estimated not to have a significant effect on the analyses of the whole structure, where the main function of the rail is to distribute the load to the posts.

The diameter of the pipes and the gap between them are the results of aesthetic analyses based on existing vehicle parapets with pipe rails and perspective drawings of different alternatives. The appearance of the parapet and visibility through it were the main focuses of the analyses. In the final stage selection was done between pipes with an outer diameter of 76.1 and 88.9 mm. The latter was chosen with a four-millimetre wall thickness. The chosen pipe has earlier been successfully used in certain vehicle parapets (see Fig. 2.14). The average centre line distance of the rail from the road surface is about the same as with present Finnish standard safety barriers for roads and bridges.

The chosen 2-pipe rail is very stiff and has a high bending strength compared to uniform open section rails. The extra capacity was accepted for aesthetic reasons. Its combined moment of inertia and elastic moment capacity about the vertical direction are 193 cm^4 and 15.4 kNm. The actual bending properties are a little lower, because a rail consisting of two separate members is not a uniform structure. If this is taken into account, for instance, by reducing the value of the lower pipe of the rail by the factor, which is defined as the proportion of the vertical distances from the road surface of the lower and upper pipe of the rail, the moment of inertia is 169 cm^4.

Handrail

The cold-rolled U-55/114/55×6 (S355MC) handrail of the Finnra H2 vehicle parapet was developed to replace the handrail earlier used in Finland, the UNP 120 (S235JR). Its tension force capacity of 435.1 kN and elastic bending moment capacity about the vertical direction of 14.4 kNm are about the same as the corresponding values of 399.5 kN and 14.3 kNm for the hot-rolled U-profile. Because the cold- and hot-rolled handrails are quite similar, it is possible to modify the vehicle parapet to accept also the hot-rolled U-profile.

Complete FEM analysis

The basic principles of the complete analysis method used here to analyse the heavy vehicle impact are described in Chapter 5.1.3. The 3D beam models (Fig. 5.5) involving geometric and material nonlinearities were built for the developed Finnra H2 vehicle parapet with different structural member alternatives and previous heavy vehicle impact-tested structures: the modified High vehicle parapet of Finnra (the Finnra H1 vehicle parapet) and the Standard vehicle parapet of SNRA.

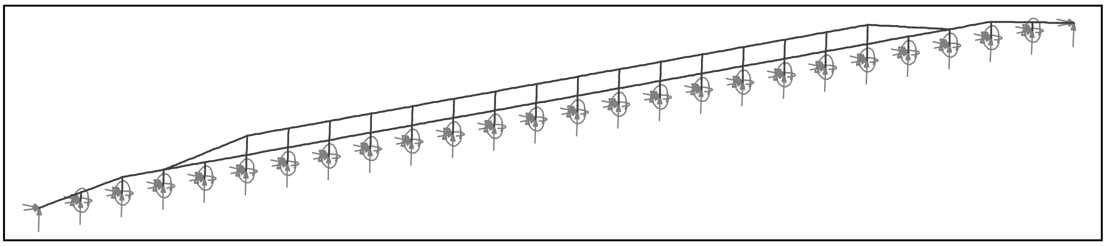

Figure 5.5 An example of an FE model of a vehicle restraint system with support reactions.

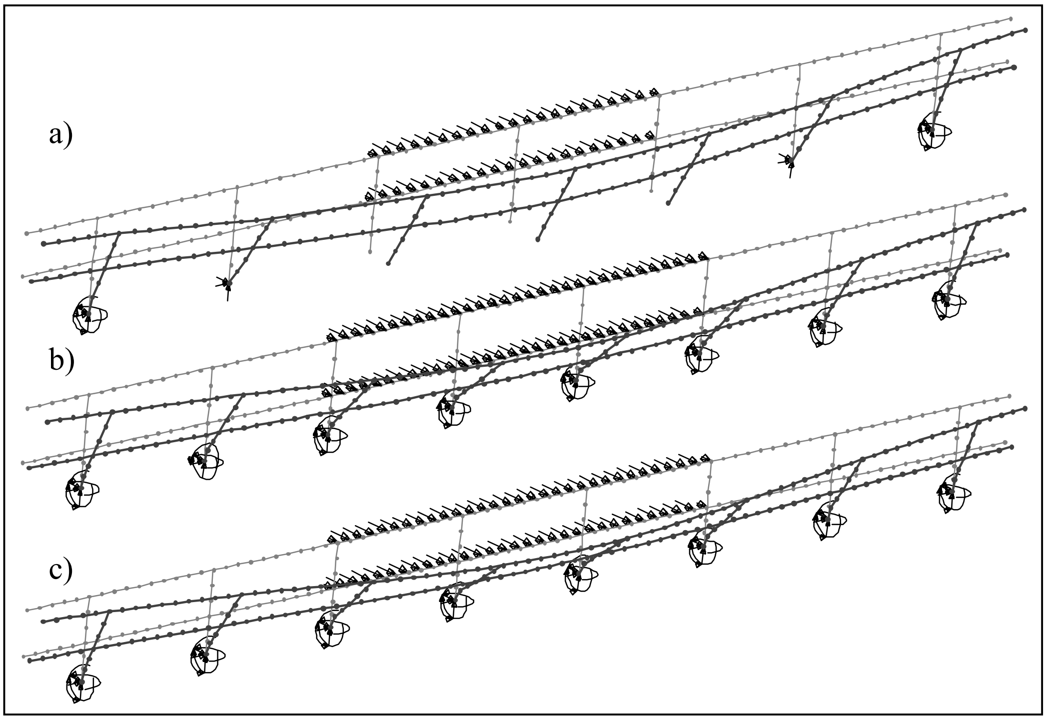

Figure 5.6 The zoomed in parts of the FE models of the vehicle restraint systems with loading, support reactions and both undeformed mesh and deformed (scale 1:1) mesh:

a) Modified High vehicle parapet of Finnra in Test TB 42
b) Standard vehicle parapet of SNRA in Test TB 51
c) Finnra H2 vehicle parapet (50×60 posts and 230/6 rail) in Test TB 51

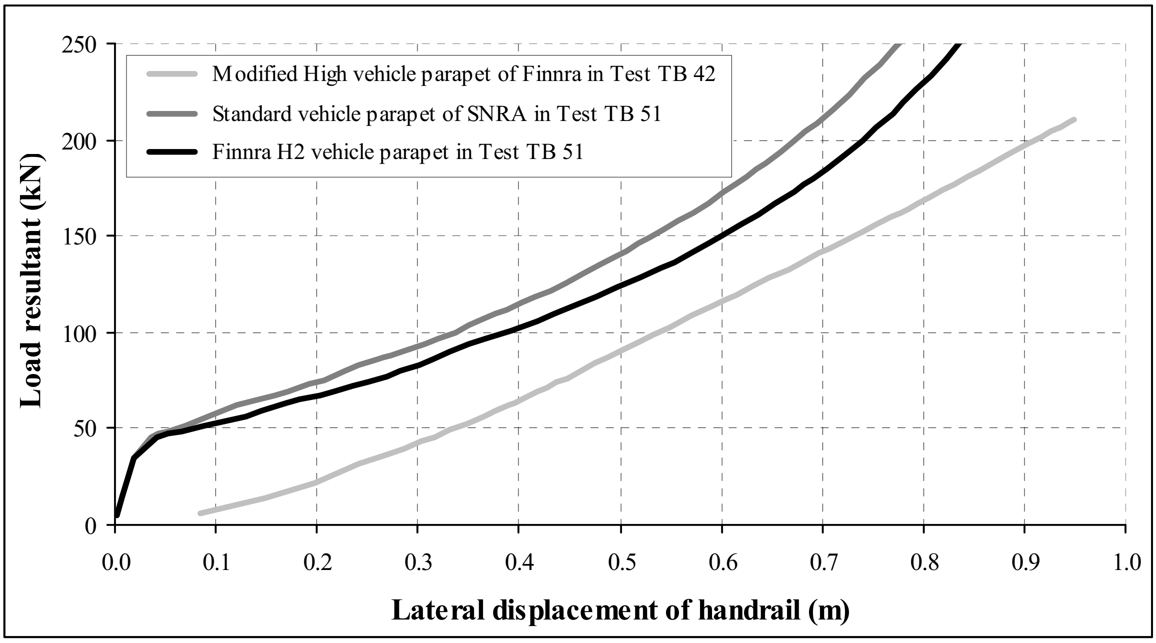

Figure 5.7 The load resultant values of the FE models of vehicle restraint systems computed as a function of the lateral displacement of the handrail. The posts are 50×60 and the rail is 230/6 in the analysis of the Finnra H2 vehicle parapet.

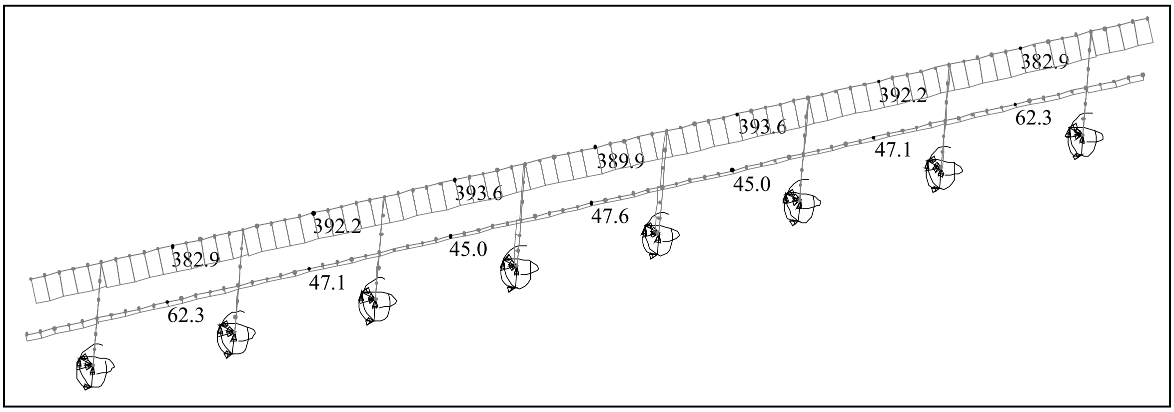

Figure 5.8 An example of the stresses obtained from the FE model for the vehicle restraint system: The tensile force of the Finnra H2 vehicle parapet (50×60 posts and 230/6 rail) near the impact area in Test TB 51 when the load resultant has reached the maximum value.

The estimated length of static knife-edge loads and their distribution between the rail and the handrail are presented in Figure 5.6 together with the deformations of the structure at the maximum load resultant value. The load of the TB 42 heavy vehicle impact test was estimated to affect a stretch two times the post spacing, while with Test TB 51 it was estimated to affect a stretch three times the post spacing. Analysis showed that the loads were distributed equally between the rail and the handrail. The functioning of the vehicle restraint systems under increased load is shown in Figure 5.7.

The maximum load resultant value in the analyses of the modified High vehicle parapet was determined by restricting the lateral displacement of the handrail to 0.95 m, which was the maximum dynamic lateral displacement in the full-scale Test TB 42 on the structure. The maximum load resultant value 250 kN used in the analyses of the Finnra H2 vehicle parapet was determined on the basis of the analyses of the standard vehicle parapet of

SNRA where the lateral displacement of the handrail was restricted to the estimated maximum dynamic lateral displacement of the structure in the full-scale Test TB 51.

An example of the stresses obtained from the FE model for the Finnra H2 vehicle parapet is presented in Figure 5.8. A similar result for the modified High vehicle parapet is presented in Chapter 5.4.2, where the calculation analyses of the Finnra H1 vehicle parapets are presented. The analyses indicated whether a structure with the chosen members achieved stability with the applied load: did the termination of the analysis due to a failure of the solution process occur and if not, were the deformations so big that there was too high risk of the parapet being brought down by a vehicle leaning heavily against it?

Vehicle parapet length and edge beam analyses

In the first stage, the above-mentioned complete analysis method was used to estimate adequate vehicle parapet length and height of the edge beam to be used in the full-scale impact tests. The European standard contains only the general requirement that the length of a safety barrier shall be sufficient to demonstrate the full performance characteristics of the system.

In previous Finnish Tests 1…3 the length of the vehicle parapet was 28 m and 32 m. The first one was used with an impact angle of 20° and the latter when the angle was 15°. In containment level H2 full-scale impact tests on the Swedish standard vehicle parapet, the tested vehicle parapet was 46.8 m long. Thus the question was whether the vehicle parapet should be longer in the tests to withstand the heavy vehicle impact of containment level H2. Short vehicle parapets were thought to be more appropriate because most bridges in Finland are short. It was, however, no use testing parapets shorter than the one used in previous Finnish tests because then the probability that the vehicle parapet ends before the impacting heavy vehicle separates from it is too big.

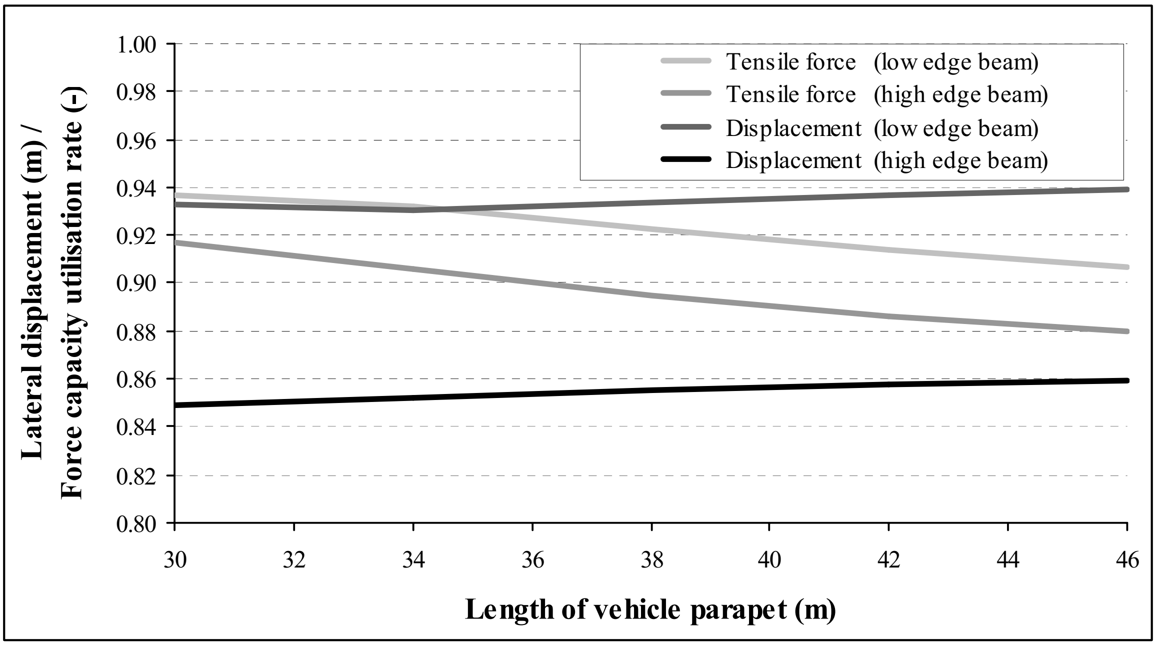

Figure 5.9 The maximum values of the tensile force capacity utilisation rate and the lateral displacement of the handrail in Test TB 51 computed from the FE model of the Finnra H2 vehicle parapet (55×55 posts and 230/6 rail).

It was decided to subject the Finnra H2 vehicle parapet to full-scale impact testing with the high edge beam because most bridges have high edge beams nowadays. Analyses were, however, done with both the high and low edge beam to see how the height of the edge beam affects the results. It was also done to find out whether the vehicle parapet tested with the high edge beam could be approved for use with the low edge beam without a new full-scale impact test, and vice versa, because the Finnra H1 vehicle parapet had been full-scale impact-tested with the low edge beam.

The FE model of the developed Finnra H2 vehicle parapet, loaded symmetrically about the vertical centre line of the model, was computed using different lengths of the parapet (30, 34, 38, 42 and 46 m) and heights of the edge beam (0 and 0.1 m) to see their effects on deformations and stresses. Examples of the results are shown in Figure 5.9. According to the analyses the length of the parapet had only a small effect on the results. Thus it was decided that, the length of the vehicle parapet in the full-scale impact test was to be the same as in previous Finnish tests.

The effect of the height of the edge beam was more significant. According to the analyses, a collision with the low edge beam was more severe than with the high edge beam. Thus the vehicle parapet that nearly failed when heavy vehicle impact-tested with the high edge beam was estimated to have a capacity problem if used with the low edge beam. If the parapet were to be tested with the low edge beam, it was estimated to probably withstand the collision of a heavy vehicle when used with the high edge beam.

5.2.3 Test 4 (TB 11)

A car weighing 937 kg collided against the parapet at 104 km/h impact speed and 20º angle (Fig. 5.10). The impact point was 0.58 m before the post. The front right-hand side of the vehicle collided heavily against the second post after the impact point. The right front wheel, the radiator grille and the windscreen became detached, and the footwell was deformed and penetrated into the passenger compartment. During the impact the car changed its direction of travel and separated from the vehicle parapet after being in contact with it for a distance of 4.6 m. After the impact the car was no longer in running condition.

Figure 5.10 The impact and the damages to test vehicle (Courtesy of HUT).

Figure 5.11 Deformation of the vehicle parapet after the impact. The tyre mark and the detached tyre of the car are shown in the picture on the right. (Courtesy of HUT)

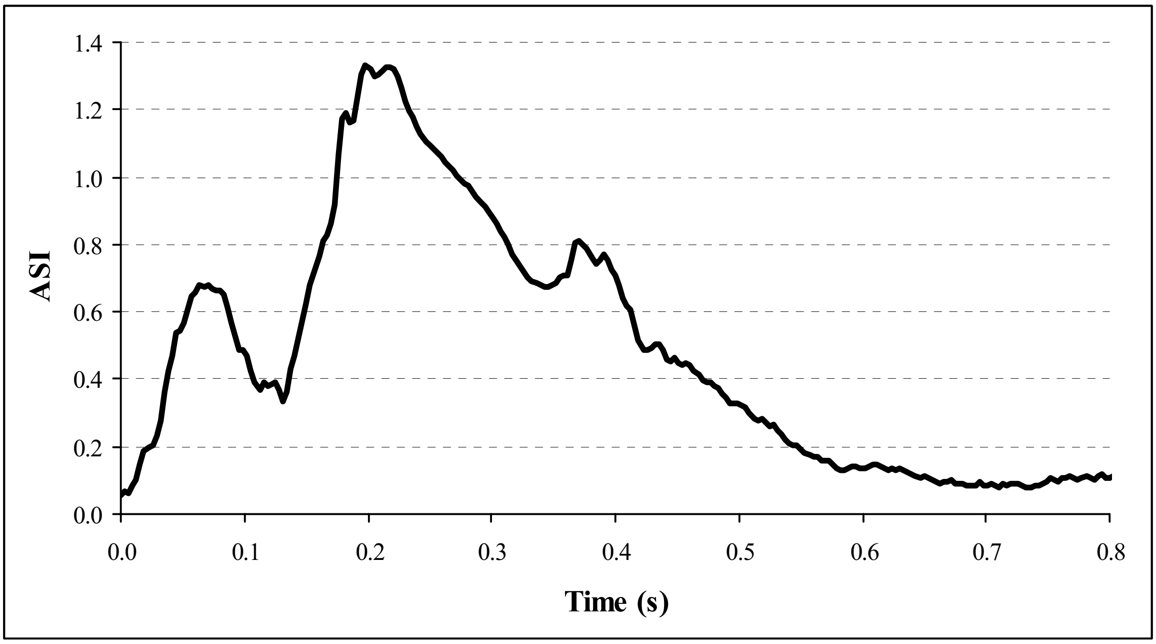

Figure 5.12 The acceleration severity index (ASI) value computed as a function of time.

The maximum dynamic lateral displacement of the vehicle parapet was 16 cm. The corresponding static value was 11 cm (Fig. 5.11). The values of the impact severity assessment indices listed below conformed to the requirements of the standard. Variation in ASI value during impact is shown in Figure 5.12.

- ASI = 1.33
- THIV = 19 km/h
- PHD = 13.5 g

5.2.4 Test 5 (TB 51)

A bus weighing 13.12 tons collided against the vehicle parapet at 81 km/h impact speed and 19.1° angle (Figs. 5.13 and 5.14). The speed was quite high compared to the requirements of the standard 70…75 km/h, due to the mistakenly set target speed of at least 80 km/h.

Figure 5.13 Impact sequence, oblique front view (Courtesy of HUT).

Figure 5.14 Impact sequence, view from above (Courtesy of HUT).

After the front right-hand side of the bus crashed into the system, the bus changed its direction of travel and the front wheels lifted off the ground. The bent parapet formed a ramp from which the vehicle rose in the air. The bus started to tilt strongly against the parapet after the rear end collided heavily against the vehicle parapet; the tilt was almost 45° at its maximum.

Figure 5.15 Deformation of the vehicle parapet after the impact (Courtesy of HUT).

After falling to the ground the vehicle went through a series of pitching and rolling movements which subsided quickly. The vehicle was not in running condition after the test. The bus were in contact with the vehicle parapet for a distance of 9.8 m. Maximum dynamic lateral displacement of the system in impact was 0.9 m. The static lateral displacement of the vehicle parapet was 0.71 m (Fig. 5.15). The working width of the vehicle parapet was 1.1 m. The parapet remained unbroken. Not a single bolt was broken.

5.2.5 Conclusions

The vehicle parapet worked in the desired way. The occupant impact severity level was low enough in the light vehicle impact and the structure withstood the heavy vehicle impact. However, the speed of the bus was over the maximum and, thus, if the standard was to be followed exactly, a new heavy vehicle test should be arranged. Finnish authorities nevertheless approved the structure as a containment level H2 vehicle parapet, because it was estimated that the excess speed did not lower the stresses to the structure. It made the impact more severe.

The bus tilted more heavily against the handrail than in the bus test on the Swedish standard vehicle parapet due to higher speed and higher tripping effect of the stiffer rail. The differences in centre of gravity height from the road surface of the used buses also had a similar effect. The centre of gravity of the bus used in the test on the Swedish standard vehicle parapet was lower. The requirements of the European standard for centre of gravity height apply only to light vehicles and the ballast of a heavy vehicle.

On the other hand, the increased lateral impact loading of the handrail due to the heavy tilting of the bus was compensated by the higher capacity of the 2-pipe rail to transfer the lateral forces to the posts than the badly flattened W rail that suffered a severe decrease in stiffness. Thus, the deformations of the vehicle parapet were estimated to correspond well with the results of the complete FE analyses when the effect of the high speed was taken into account.

The vehicle parapet was tested with the high edge beam into which the posts were grouted. The structure is also approved by authorities for use also when bolt fixing of the posts with base plates is used and/or the parapet is installed on a low edge beam. The base plate approval is based on the calculation analyses made during the development of the Finnra H2 vehicle parapet with the 240/6 rail where impact tests were also conducted using bolt fixing of the posts.

The parapet was estimated to withstand the increased stresses of a heavy vehicle impact caused by the lowering of the edge beam, because the vehicle parapet has extra capacity as proved by excess speed in the bus test. To avoid an increase in occupant impact severity in case of a light vehicle impact, due to the increased gap between the rail and the lower edge beam, it was decided to equip the parapet with a lower pipe rail. The lower rail is similar to the one used with the 240/6 rail of the Finnra H2 vehicle parapet, and is based on the impact tests on that structure.

It would have been a good idea to test the functioning of the vehicle parapet with the low edge beam, at least in case of a light vehicle impact, which may be sensitive even to small changes. The authorities have, however, decided not to test it for now, because the low edge beam is rarely used anymore. Adequate capacity against a heavy vehicle collision, where the risk of severe consequences is higher than in a light vehicle impact was considered more important, and this requirement was estimated to be more likely fulfilled by using the results of the complete FE analyses. According to the calculations, the extra lateral displacement of the handrail due to the lowering of the edge beam has about the same effect as excess speed: the difference between the corresponding values of the FE analysis and the full-scale impact test with higher impact speed.

The price difference between the developed vehicle parapet and the present standard vehicle parapet was considered acceptable, because the new parapet weighs more and has higher structural capacity. The weight of the Finnra H2 vehicle parapet is about the same as that of the Swedish standard vehicle parapet.

5.3 Finnra H2 vehicle parapet with 240/6 rail

5.3.1 Developed structure

The 240/6 uniform open section rail (Rautaruukki Oyj) was developed to be used instead of the first impact-tested 2-pipe rail in the Finnra H2 vehicle parapet described in Chapter 5.2.1. It is meant for small bridges whose parapets are desired to have the same kind of rail as the safety barriers on roads to give a uniform look to roadside. The Finnra H2 vehicle parapet on a high edge beam equipped with the 240/6 rail (Fig. 5.16) weighs about 56 kg/m (expansion joints included) and costs about 60 per cent more than the present Finnish standard vehicle parapet. The weight and the price are higher than with the 2-pipe rail.

The extra weight comes from the lower pipe rail, which is needed with the 240/6 rail to prevent severe collisions of light vehicles against the posts. For the same reason the rail is equipped with lipped omega section deformation elements, which absorb energy and increase the distance of the rail from the posts. The weights and prices of different structural alternatives are about the same if the parapet is on the low edge beam, because then a lower rail is needed also with the 2-pipe rail.

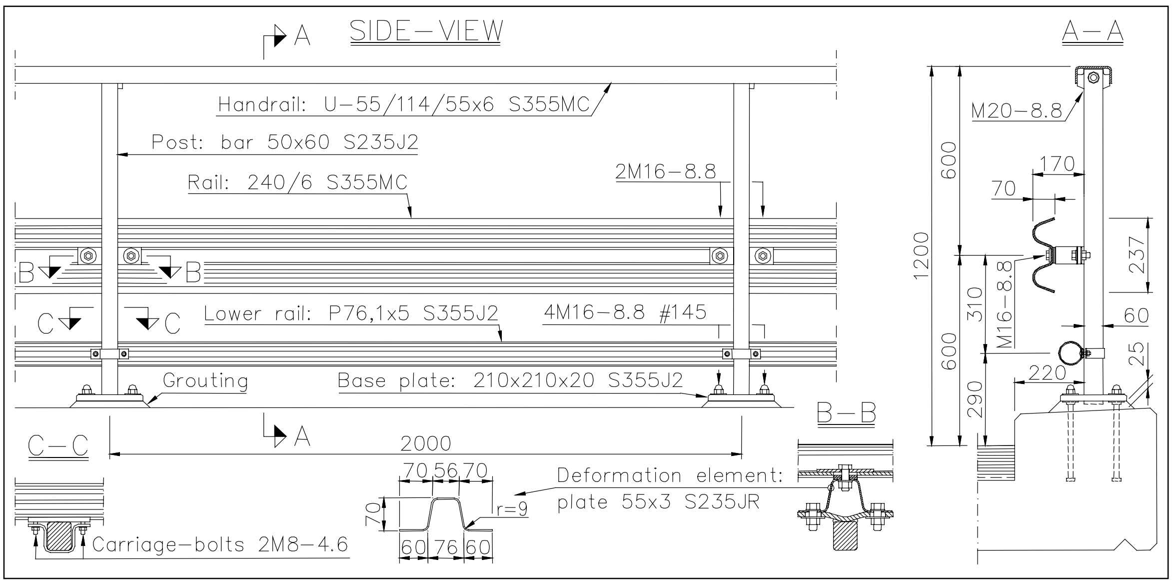

Figure 5.16 General drawing of the Finnra H2 vehicle parapet with 240/6 rail.

5.3.2 Calculation analyses

Overview

The Finnra H2 vehicle parapet with the 2-pipe rail was tested before the open section rail and verified to conform to the requirements of the European standard. In the tests the posts were grouted into the holes of the edge beam. The calculations presented here are related to the changing of the rail and to the modification of the posts' fixing to the edge beam. Analyses of both single structural components and the whole structure were performed. The latter was done with the Nordic simulation application, before the final full-scale car test, to get experience from the application for possible future use.

Rail

The moment of inertia and elastic moment capacity about the vertical direction of the open section 230/5 rail currently used in Finland and the W rail (306/3), which passed impact tests satisfactorily for use with the Swedish standard vehicle parapet with a post spacing of 1.8 m, are quite similar although the W rail is a little stiffer (Table 5.3). It is notable that the denser post spacing of 2.0 m used in Finland leads to higher stresses in the rail during impact.

The bending properties of the new open section rail to be used with the Finnra H2 vehicle parapet have to be better than those of the W rail due its longer span. It was estimated that the difference does not necessarily need to be significant, because by using thicker plate the additional stresses due to the longer span can be offset. An open section of three-millimetre plate flattens easily during vehicle impact thereby losing much of its capacity. Small thickness also means problems with snow clearance. According to Finnish experiences, thickness of the plate must be at least four millimetres with the open section rail and three millimetres with the closed pipe rail to withstand small impacts from snow clearance equipment without notable damages.

The development of the new open section rail was realised so that the manufacturer (Rautaruukki Oyj) can produce the profile with the same cold forming machine as the currently used rail after small adjustments. Maximum thickness of the plate was six millimetres due to manufacturing reasons. Several different open section rails of S235JR steel were developed. The first version was cold-rolled with the same roll adjustment of otherwise similar but 30 mm wider plate than is used for the 230/5 rail. As a result, the length of the oblique flanges increased so that the height of the profile increased from 232 mm to 242 mm. Another developed alternative 230/6 rail was like the 230/5 rail but of one-millimetre thicker plate.

Table 5.3 The moment of inertia (I) and the elastic moment capacity (M_u) about the vertical direction of different rails of the vehicle parapets. The values were computed from the cross-sections of the rails.

Vehicle parapet	Swedish standard	Present Finnish	Finnra H2 vehicle parapet			
			2-pipe [1]	Alternative of open uniform sections		
Rail type	W rail	230/5	2P88.9×4	240/5	230/6	240/6
Steel	S235JR	S235JR	S355J2	S235JR	S235JR	S355MC
I (cm^4)	102	90	193	112	100	107
M_u (kNm)	5.8	6.4	15.4	5.9	7.2	10.3

1) Combined values without the non-uniformity reduction (see Chapter 5.2.2).

After several different kinds of rail alternatives the 240/6 rail, of stronger S355MC steel, was finally designed and chosen for use. The plate used for it is not as wide as was designed for the 240/5 rail to avoid changing the cutting tool of the production line. The designed 240/6 rail could have been modified to have about similar bending properties as the earlier tested 2-pipe rail by using 60/140/60×7 U-profile (S355MC) behind it. Their combined moment of inertia and elastic moment capacity about the vertical direction would have been 162 cm^4 and 14.8 kNm.

If U-profile had been used, the need to replace the 2-pipe rail with the open section rail could have been theoretically proved without new impact tests. The U-profile was nevertheless chosen because the pipes have excess rigidity, which was not desired to reach, and the effects of the changing of the rail on impact severity of the vehicle parapet could not have been proven with adequate certainty without the light vehicle impact test.

Deformation elements

After a couple of light vehicle tests the rail was equipped with deformation elements which are a modification of the earlier developed and tested lipped omega section deformation elements presented in Chapter 5.4.2. The developed deformation element was analysed by the 3D shell element model involving geometric and material nonlinearities (Fig. 5.17) to find out the value of the collapsing force (5.18). The leaning of the loaded surface against the rail was modelled by using the planar surface constraint equation: a surface may translate and/or rotate but is constrained to remain a plane.

The value of the collapsing force seemed to be high enough to withstand small impacts, for instance, from snow clearance equipment. The post starts to yield from the root at about the same time as the deformation element collapses, because the collapsing force multiplied by the vertical distance of the rail centre line distance from the top surface of the high edge beam is about the same as the elastic moment capacity of the post, which is high enough to withstand impacts from snow clearance equipment.

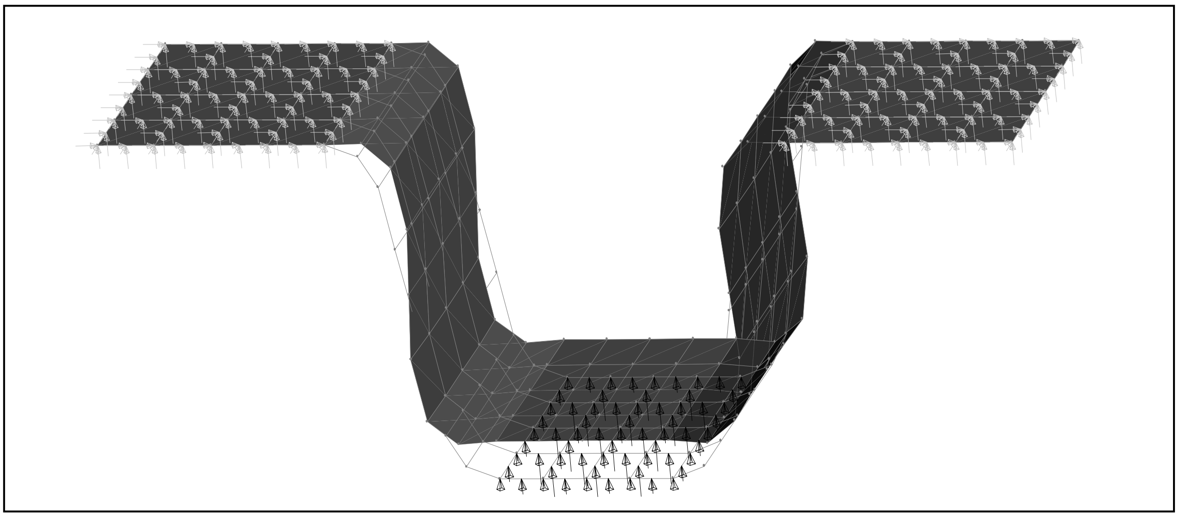

Figure 5.17 An FE model of the lipped omega section deformation element with loading, support reactions and both undeformed mesh and shaded deformed mesh. Planar surface constraint equation is assigned to the loaded area.

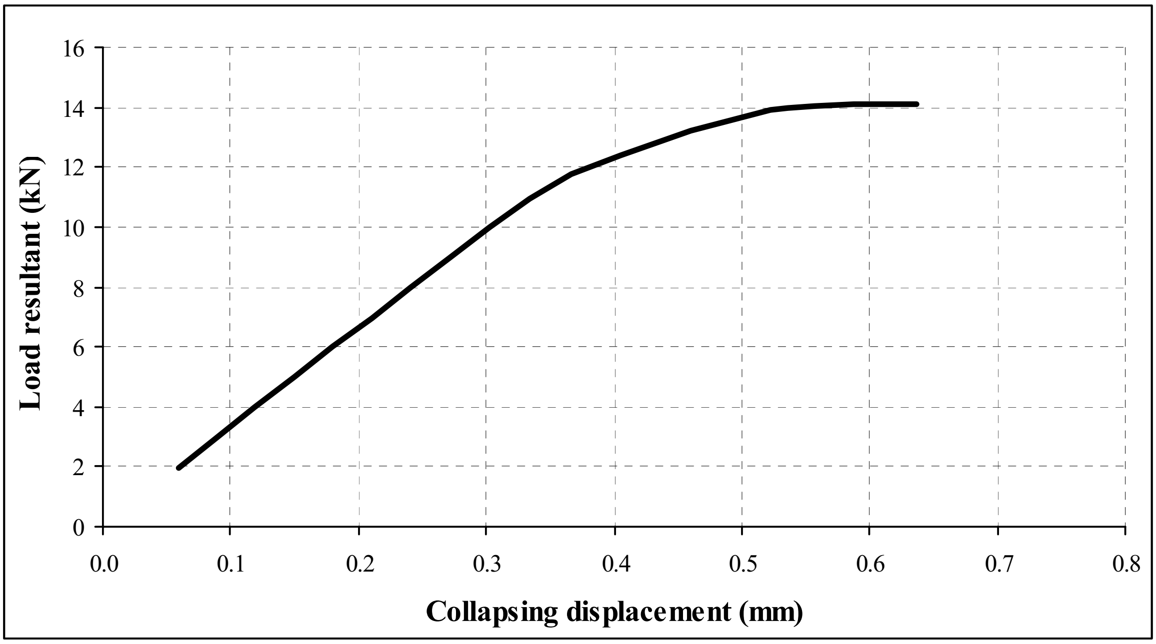

Figure 5.18 The load resultant value of the FE model of the lipped omega section deformation element (width 70 mm, plate 55×3, steel S235, bending radius 9 mm) computed as a function of collapsing displacement. The maximum value of the load, collapsing force, is 14.1 kN.

The collapsing force was also estimated to be low enough to dampen the impact of the vehicle against the rail. A too high collapsing force would have made the structure too rigid and might had prevented the designed functioning of the deformation element as shown by the comparison of Tests 6 and 7 on the Finnra H1 vehicle parapet with a 2-pipe rail presented in Chapter 5.4.3.

Lower rail

After the first light vehicle test the vehicle parapet was equipped with a lower rail to prevent a heavy impact from a vehicle against the post. Several different kinds of pipe lower rails were impact-tested (Table 5.4). The first tested P48.3×2.6 pipe was the same one developed as the middle rail of the Finnra H2 vehicle parapets. Middle rails are used to reduce the size of the openings in parapets for the safety of pedestrians. The impact test showed that the middle rail has too low structural capacity to be used as a lower rail. For the next test, it was replaced by a bigger P76×4 pipe with significantly better moment of inertia and elastic moment capacity. Later, as a final adjustment, the thickness of the pipe was increased by one millimetre.

Table 5.4 The moment of inertia (I) and the elastic moment capacity (M_u) about the vertical direction of different pipe (S355J2) alternatives for the lower rail of the vehicle parapet.

	P48.3×2.6	P76×4	P76×5
I (cm^4)	10	71	82
M_u (kNm)	1.4	6.6	7.6

Base plates

The Finnra H2 vehicle parapet with a 2-pipe rail was tested so that the posts were grouted into the holes. The bolt fixing with base plate presented here was developed before the impact tests with the 240/6 rail and was used in all tests with the 240/6 rail.

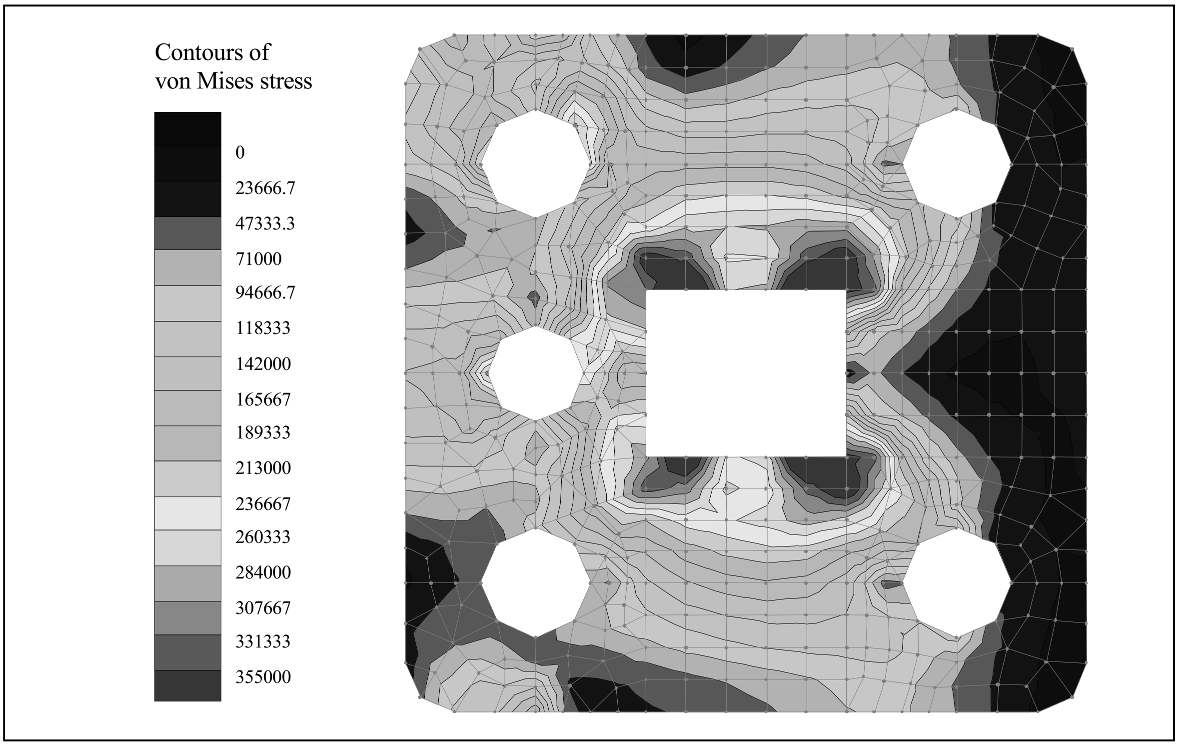

Figure 5.19 An example of an FE model of the base plate with the results of the von Mises stress.

The base plate was modelled by a 3D shell element model involving geometric and material nonlinearities as well as boundary condition nonlinearity with concrete grouting under the base plate. The plate has four round holes for the bolts, one smaller round grouting hole and one big rectangular hole for the post penetrating through the plate (Fig. 5.19).

The modelled base plate was resting on a Winkler-type foundation: the bolts were modelled as elastic springs around the holes of the bolts and the concrete grouting was modelled as a bed of elastic springs with a zero lift-off force. The plastic bending moment of the post loaded the base plate. It was modelled as a vertical force couple on the edge of the rectangular hole. The supporting effect of the fillet welds around the post on the top and bottom surface of the base plate was taken into account by using around the rectangular hole the straight line constraint equations: a line may translate and/or rotate but is constrained to remain straight.

The plate was first designed to be a rectangular with the same width (250 mm) as the Swedish and the present Finnish standard vehicle parapets, and with the same M20 8.8 bolts and distances between them (grid # 160 mm) as with the present Finnish standard vehicle parapet. After several analyses the suitable thickness of the plate was estimated to be 20 mm (S355J2). The plate of the present Finnish standard vehicle parapet is 15 mm (S355J2), while that of the Swedish standard vehicle parapet is 25 mm (S235JR).

In the analysis of the chosen plate plastic yield occurred only in the corners of the rectangular hole. The hole rotated about 0.5° around the horizontal axes which caused extra lateral displacement of less than one centimetre of the handrail. The additional lateral displacement was so small that the fixing detail of the post to the edge beam was estimated not to have a significant effect on the impact test results, and thus the base plate was approved for use also with the 2-pipe rail even though it was not tested with them. The decision was on the safe side because there is extra capacity in the Finnra H2 vehicle parapets as proved by the excess speed of heavy vehicle Test 5.

Later the base plate was modified. The modifications did not have significant effects on the stress results for the plate. First it was decided to make the plate smaller due to the inconsistent appearance of a small post and a big plate. The plate was made as small as only the horizontal location tolerance of the bolts allowed. The result of the analysis of that 20×210×210 plate with # 130 mm as the grid of the bolts is presented in Figure 5.19.

Later, before the impact tests, the bolts were changed to the smaller M16 8.8 ones with wider spacing (grid # 145 mm). It was done for the sake of appearance and to make space for the connected structures like the diagonal anchor of the handrail and the protection wall against direct contact with adjacent live parts of an electrified railway overhead contact line system. Original M20 (tension force capacity 125 kN) bolts were too big, because the computed tension force of the bolts in a normal base plate connection is, at the maximum, about 30 kN and about 1.5-fold in a diagonal anchor connection, while the tension force capacity of the M16 8.8 bolt is 80 kN.

Nordic simulation application

Before the last full-scale light vehicle impact test, the functioning of the last modified version of the Finnra H2 vehicle parapet in the car impact test was analysed by the Nordic simulation application. Analyses were also done after the full-scale impact test to see how the higher impact speed affects the impact severity assessment indices. However, the post-analyses were made only by increasing the impact speed. The computer model was not calibrated.

The analysis company was FORCE Technology. The results presented here are based on letters and reports (Sangø 2003) received from Mr. Fredrik Sangø. The impact point was designed to be at the post to make the analysis compatible with the previous full-scale light vehicle tests on that structure, but some test simulations were also done with the impact point 1.3 m before the post.

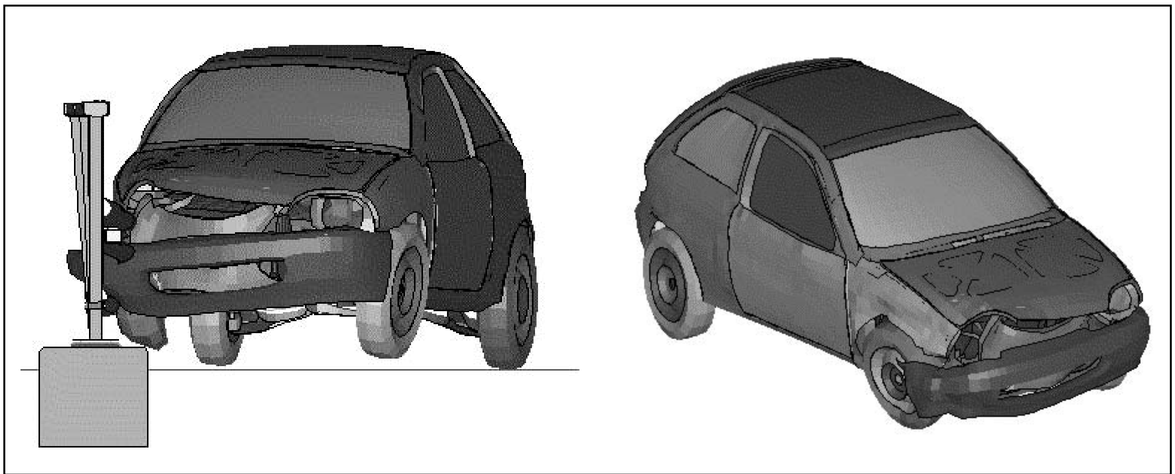

Figure 5.20 Simulated impact of Test TB 11 against the Finnra H2 vehicle parapet with 240/6 rail and the car after the impact (compare with Fig. 5.25). (Sangø 2003)

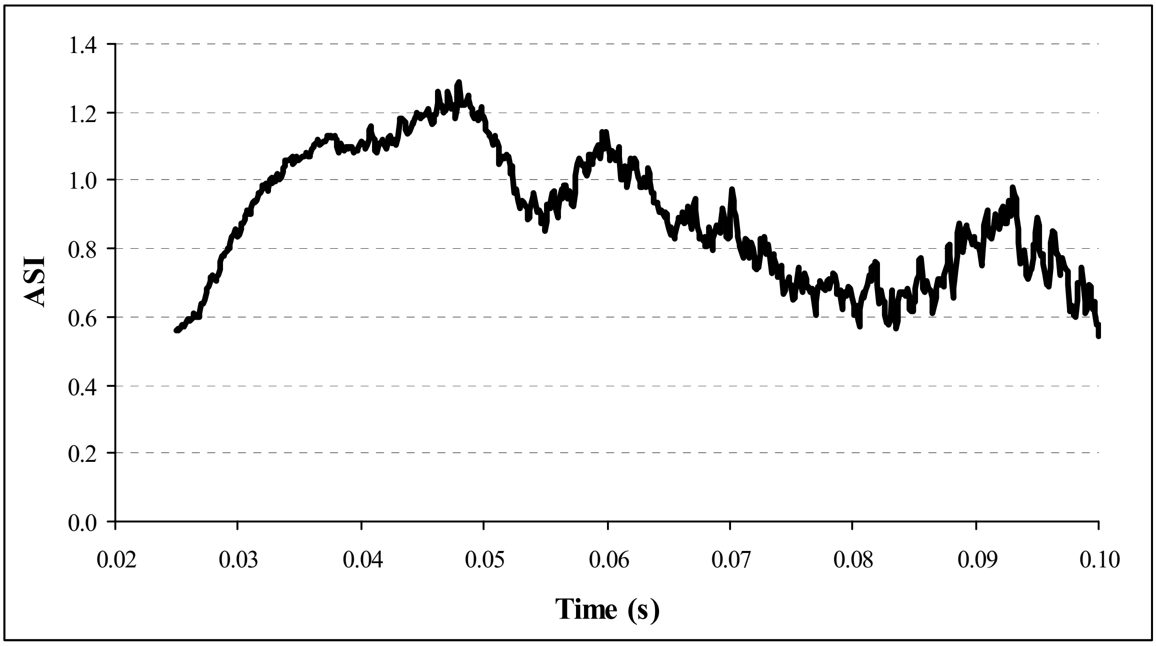

Figure 5.21 The acceleration severity index (ASI) value computed as a function of time (Sangø 2003).

In the main analysis a GeoMetro car weighing 900 kg collided against the vehicle parapet (impact point at the post) at 100 km/h impact speed and 20º angle (Fig. 5.20). During the impact the car changed its direction of travel and separated from the vehicle parapet after being in contact with it for a distance of about three metres. After the impact, the car was no longer in running condition. The whole vehicle more or less sustained plastic deformations. Strongest deformations occurred in the initial impact area of the vehicle, that is, in the front right-hand side of the car.

The maximum lateral displacements of the handrail were 10 cm (dynamic) and 8 cm (static), while the corresponding values for the rail equipped with deformation elements were 19 cm and 15 cm. The static collapsing displacements of the deformation elements were at a maximum 40 mm. According to the simulation, the vehicle parapet fulfilled the requirements of Standard EN 1317. The values of the impact severity assessment indices are listed below. A more precise presentation of the acceleration severity index is given in Figure 5.21. Values in brackets are from the simulation with the higher impact speed of 107 km/h.

- ASI = 1.29 (1.27)
- THIV = 32 km/h (38 km/h)
- PHD = 7.1 g

The ASI values of the test simulations using the other impact point were analysed and they also fulfilled the requirements. The values were 1.39 and 1.40 while the impact speeds were 100 km/h and 107 km/h, respectively.

5.3.3 Tests 8, 9, 10 and 12 (TB 11)

The Finnra H2 vehicle parapet with the 240/6 rail was tested four times. The measurement data on the vehicle and the parapet are presented in Table 5.5.

Table 5.5 Measurement data on vehicle and vehicle parapet.

Test	Weight [kg]	Speed [km/h]	Angle [°]	Impact point before post (m)	Length of contact (m)	Max. dynamic deflection (m) [1]	Max. static deflection (m) [1]
8	901	110	20	1.75	— [2]	— [2]	0.10
9	872	104	20	1.75	4.75	0.14	0.07
10	897	100	20	0.16	3.39	0.17	0.12
12	872	107	20	0.32	3.12	0.12	0.03

1) The maximum deflections presented here are deflections of the handrail. In Tests 10 and 12 the rail was subjected to the biggest static deflections due to the collapse of the deformation elements. Dynamic deflections of rails were not measured.

2) Not measured. The report on Test 8, which clearly did not conform to the requirements of the standard, is a light version due to cost saving.

The first tested structure had neither deformation elements nor a lower rail. The nose of the car collided heavily against the first post after the impact point with an impact speed over the maximum allowable value of 107 km/h (Figs. 5.22 and 5.26). The vehicle was damaged badly in the crash being no longer in running condition after it. The right front wheel, the radiator grille, the bonnet and the windscreen became detached. The footwell was strongly deformed and penetrated into the passenger compartment and other big deformations also occurred in the compartment.

Figure 5.22 Test 8: The impact and the damages to the test vehicle (Courtesy of HUT).

Figure 5.23 Test 9: The impact (Courtesy of HUT) and the damages to the test vehicle (Courtesy of A-Insinöörit Oy).

Figure 5.24 Test 10: The impact and the damages to the test vehicle (Courtesy of HUT).

Figure 5.25 Test 12: The impact (Courtesy of HUT) and the damages to the test vehicle (Courtesy of A-Insinöörit Oy).

After Test 8 it was obvious that a heavy impact of the vehicle against the post must be prevented somehow. As serious problems did not occur with the earlier tested 2-pipe rail because it has a higher bending stiffness and, above all, it works better than the open section with a low torsional stiffness when the impact is strongly focused on the lower edge of the rail.

A good way to improve the functioning of the Finnra H2 vehicle parapet with the 240/6 rail would be to decrease the vertical distance of the rail from the road surface. The 600 mm distance between the centre line of the 240/6 and the road surface is the same as with the present Finnish standard safety barriers on roads and bridges. That distance in the case of standard structures was earlier 550 mm, but it was increased in the mid-1990’s due to the impact resistance requirements of safety barriers on roads. For example, in the case of the Swedish standard vehicle parapet the gap between the rail and the edge beam is less, because the open section rail is higher and its centre line is 550 mm above the road surface.

Having different rail levels on roads and bridges was not considered to be in line with the purpose of the 240/6 rail, because the rail was developed to be used instead of the normally used 2-pipe-structure to create a uniform look for the safety barriers on roads and bridges. Thus, it was decided not to decrease the vertical distance of the rail from the road surface.

The raising and reshaping of the edge beam, as was done in Norway (see Fig. 4.20), and the adding of the lower rail under the 240/6 rail were considered other possibilities for preventing severe collisions against posts. The first alternative was rejected because the desire was to use similar edge beams with all different parapet structures. Therefore, it was decided to add the lower rail.

The lower rail was also chosen because it is a member which would in any case often be part of the vehicle parapet as the middle rail. The vehicle parapet without any additional equipment to reduce the size of the openings can be used only if pedestrian traffic on the bridge is prohibited with a traffic sign. If not, at least middle rails over and above the rail are needed. For Test 9 the vehicle parapet was equipped with a P48.3×2.6 (S355J2) middle rail as a lower rail.

The added lower rail worked partly as planned. It bended and got squashed near the post, but did not break and dampened the collision of the vehicle against the post (Figs. 5.23 and 5.27). The nose of the car did not go as far behind the rail than in the earlier test, and the right front wheel was not totally detached. The collision against the first post after the impact point was still quite heavy. The right front wheel became partly detached and penetrated into the vehicle while the bonnet and the windscreen became totally detached.

Figure 5.26 Test 8: Deformation of the vehicle parapet after the impact. The tyre mark and the detached tyre of the car are shown in the picture on the right. (Courtesy of HUT)

Figure 5.27 Test 9: Deformation of the vehicle parapet after the impact. The tyre mark of the car is shown in the picture on the right. (Courtesy of A-Insinöörit Oy)

During the impact the right A-pillar of the car went through major movements partly due to the penetrating wheel. The movements of the pillar warped the roof of the car and finally led to a situation where the main supporting effect of the pillar against body of the car was lost and further deformations could easily arise. After the first and heaviest collision the vehicle continued its travel parallel to the vehicle parapet and scratched against the parapet from time to time. Thus, part of the damages to the car, which was not in running condition after the impact test, were caused by post-impacts against the parapet.

To make the impact against the posts less severe, the lower rail was replaced with a bigger P76.1×4 pipe and equipped with deformation elements. Lipped omega section deformation elements were added to absorb impact energy and to increase the distance of the rail from the posts. Because the deformation elements made the construction wider, the distance of the vehicle parapet posts from the inner edge of the edge beam was increased so that the effective width of the bridge remained unchanged.

Made modifications worked quite well in Test 10. Damages to the car were less notable, but the impact was still too severe (Figs. 5.24 and 5.28). The car hit against the second post after the impact point. During the impacts the car changed its direction of travel and separated from the vehicle parapet being no longer in running condition. The windscreen became detached, but not the right front wheel.

Figure 5.28 Test 10: Deformation of the vehicle parapet after the impact. The tyre mark of the car is shown in the picture on the right. (Courtesy of A-Insinöörit Oy)

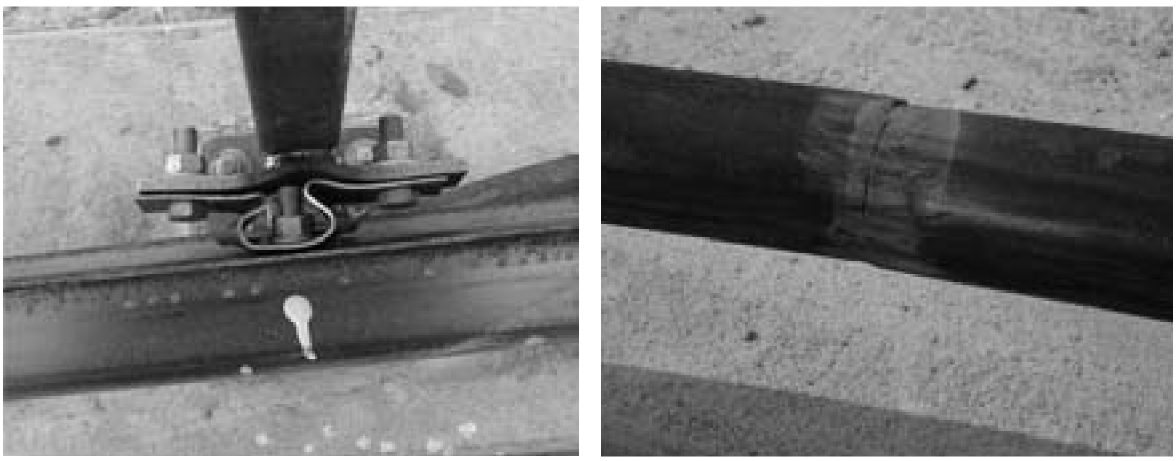

Figure 5.29 Test 10: Functioning of the deformation element (Courtesy of HUT) and fracture of the lower rail (Courtesy of A-Insinöörit Oy).

A heavy impact against the post was prevented in Test 10, but the results would have been better, if the structure had been constructed as it was designed. The deformation elements were wrongly installed, so that the bolts limited their collapsing displacement, and there was an extra weld joint in the lower rail in the impact area (Fig. 5.29). The added weld joint of the lower rail was not a full strength joint, because it was done without a backing ring, and thus it fractured and increased the deformation of the lower rail.

For the next test the deformation elements were installed correctly and for a safety margin the lower rail was also replaced with a pipe with one-millimetre thicker walls. The modified construction was first tested with a bus (see Chapter 5.3.4). After the functioning of the parapet was verified in the heavy vehicle test, occupant impact severity was checked. This was done first by analysing the structure with the Nordic simulation application, according to which the vehicle parapet conforms to Standard EN 1317, and then by arranging Test 12.

In Test 12 a car hit slightly against the second post after the impact point at the maximum allowable impact speed so that the radiator grille, the bumper and the windscreen became detached. During the impacts the car changed its direction of travel and separated from the vehicle parapet being no longer in running condition. The modifications made to the vehicle parapet worked as intended.

Figure 5.30 Test 12: Deformation of the vehicle parapet after the impact (Courtesy of A-Insinöörit Oy).

Figure 5.31 Test 12: Functioning of the connections between the rail and post (Courtesy of A-Insinöörit Oy).

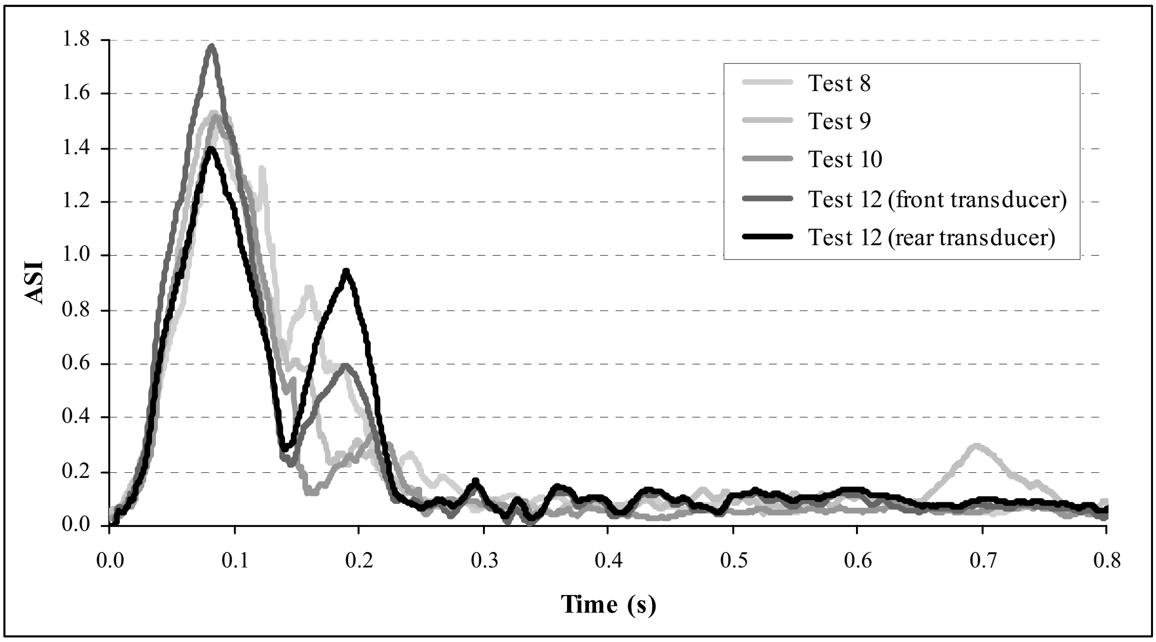

Figure 5.32 The acceleration severity index (ASI) values computed as a function of time.

The collision was smoother, which can be seen by comparing the impact moment photos of Test 12 (Fig. 5.25) to the photos of earlier tests. The lower rail did not fracture this time, and it prevented the heavy collision of the vehicle against the post (Fig. 5.30). Also, the deformation elements worked as intended. The static collapsing displacements were at a maximum 30 mm (Fig. 5.31). However, the results were not in line with previous tests. The impact severity assessment index values were notably higher than expected.

There were two transducers in the car in Test 12. The final test parameter values are combinations from the transducers weighted by their distance from the vehicle's centre of gravity. According to the front transducer, which was situated near the vehicle's centre of gravity, ASI and THIV were over the maximum values of 1.4 and 33 km/h. The values from the rear transducer fulfilled the requirements of the standard. As notable difference between the transducer readings did not occur in previous tests. If rotation is presumed to occur around the vehicle's centre of gravity, the acceleration values are higher the farther the transducer is from centre of gravity. However, in made full-scale light vehicle impact tests the higher values have often occurred with front transducer.

Impact severity assessment indices computed from the results of different tests are presented in Table 5.6. Variations in ASI values during the impacts are shown in Figure 5.32 where instead of the combined value the results of transducers are presented separately in case of Test 12.

Table 5.6 The impact severity assessment indices. The values from the rear transducer in Test 12 are presented in brackets.

Test	ASI	THIV [km/h]	PHD [g]
8	1.50	39	15
9	1.53	35	13
10	1.51	37	5.7
12	1.79 (1.39)	39 (33)	7.1

5.3.4 Test 11 (TB 51)

A bus weighing 13.08 tons collided against the vehicle parapet at 72 km/h impact speed and 19.5º angle (Figs. 5.33 and 5.34). The behaviour of the vehicle was quite similar to an earlier bus test on the vehicle parapet with a 2-pipe rail presented in Chapter 5.2.4, except that the impact on the parapet was not as severe. The tilt of the vehicle against the parapet was 26° at the maximum. It was considerably less than in the test with the 2-pipe rail due to the lower impact speed and the lower bending stiffness of the rail.

The bus was in contact with the vehicle parapet for a distance of 11.05 m. Maximum dynamic lateral displacement of the system in impact was 0.64 m. The static lateral displacement of the vehicle parapet was 0.60 m (Fig. 5.35). The working width of the vehicle parapet was 0.9 m. The rail and deformation elements worked as planned. The rail maintained it cross-section well. Deformation elements' collapsing displacement was at its maximum near the impact point. The deformation of the lower rail showed its uselessness in a heavy vehicle collision. After the impact the lower rail was almost straight. Only a couple of fastening parts between the lower rail and the posts were detached.

Figure 5.33 Impact sequence, view from the front (Courtesy of HUT).

Figure 5.34 Impact sequence, view from above (Courtesy of HUT).

Figure 5.35 Deformation of the vehicle parapet after the impact (Courtesy of A-Insinöörit Oy) and the functioning of the deformation element (Courtesy of HUT).

5.3.5 Conclusions

The authorities have not yet decided whether to approve the vehicle parapet or whether more development is needed. The last full-scale light vehicle test gave contradictory results, while run computer simulations support approval. It is possible that the vehicle parapet will be approved for the time being, and the situation will be reassessed in connection with the next revision of the standard, which may include new requirements for impact severity assessment indices. After all, the structure will not be very common. It is meant for small bridges and is more expensive than the 2-pipe rail alternative. It is also possible that more simulations will be run to better understand the results of the last full-scale impact test.

Several light vehicle tests on the vehicle parapet were conducted to find suitable structures to prevent the heavy impact of the car against the post. The damages to the car were less notable after each modification. The developed additional structures, deformation elements and the lower rail, worked as hoped, but they had to be adjusted to make the parapet meet the requirements of the standard. Light vehicle impact tests were used as an adjustment tool.

The last modification of the vehicle parapet conforms to Standard EN 1317 according to simulations made with the Nordic simulation application. In the full-scale impact test the front transducer near the vehicle's centre of gravity gave too high impact severity assessment index values, while according to the rear transducer the vehicle parapet would fulfil the requirements of the standard. The results received from the front transducer were not in line with previous tests. It may indicate that there have been, for instance, some major additional movements near the transducer due to the plastic deformation of the car body. However, in this case no clear reason for rejecting the results from the front transducer was found.

It is also possible that the higher impact severity assessment index values in the full-scale impact test are due to higher impact speed. Simulations before the full-scale impact test were done at the lower impact speed of 100 km/h. After the full-scale impact test some simulations were done at the higher impact speed of 107 km/h. The simulations gave about the same THIV value as the full-scale test, so it is possible that the high THIV value is a result of the excessive impact speed. There were hardly any changes in ASI values when the impact speed was increased. Thus, the simulations did not clarify the high ASI value problem. The reason for the small changes between the ASI values in simulations with different impact speeds might be that the computer model of the simulated impact of Test TB 11 is calibrated only to the impact speed of 100 km/h.

In the heavy vehicle impact test there was no problem with the vehicle parapet. The structure worked better in the bus test with the 240/6 rail than with the 2-pipe rail. The 240/6 rail did not trip the bus against the handrail as heavily as the stiffer 2-pipe rail. It also did not flatten like the W rail in the bus test on the Swedish standard vehicle parapet; thus it transferred the lateral forces to the posts better than the W rail that suffered from a severe decrease in stiffness. Due to the concentration of the load against the rail, the lateral displacement increased with the rail and decreased with the handrail compared to the previous Finnish and Swedish tests. The lower rail that is needed in the case of light vehicle collision did not have much influence on the impact performance of the heavy vehicle due to its small distance from the road surface.

The vehicle parapet was tested with the high edge beam by using base plates and bolts to anchor the posts to the edge beam. Grouting of the posts into the holes of the edge beam is also possible, because, according to made analyses, different post fixing details do not have a significant effect on the impact-functioning of the parapet. The developed vehicle parapet has enough capacity against a heavy vehicle impact even if installed on the low edge beam, because it worked better in the bus test than the 2-pipe rail structure, which is approved for use both with high and low edge beams. In the case of a light vehicle impact there is no certainty that the structure would fulfil the requirements of the standard, but the policy concerning it is the same as with the 2-pipe rail.

Due to the lower rail, the vehicle parapet with the 240/6 rail is more expensive than the 2-pipe rail alternative which does not need a lower rail if installed on the high edge beam. Thus, it would have been more economical to decrease the vertical distance of the 240/6 rail from the road surface and try to manage in the impact tests without the lower rail. But then the structure would not blend into the road environment as well because with a safety barrier on the road the rail would be on a higher level.

5.4 Finnra H1 vehicle parapets

5.4.1 Developed structures

The Finnra H1 vehicle parapet is a modified High vehicle parapet meant mainly for rehabilitation and repair of bridges where there is the present standard vehicle parapet and containment level H1 is adequate. The basic alternative is to equip the rail with pipe deformation elements (Fig. 5.36) which increase the steel weight of the structure a couple of kilos per linear metre of the vehicle parapet and the price about 5 per cent compared to a new High vehicle parapet.

A more aesthetic appearance can be achieved by using 2-pipe rail (Fig. 5.37) similar to the Finnra H2 vehicle parapet. Then the final weight of the parapet is about the same as originally, but the total amount of the added steel parts (2-pipe rail and deformation elements) is about 15 kg/m (expansion joints included) and the price about 10 per cent higher compared to a new High vehicle parapet.

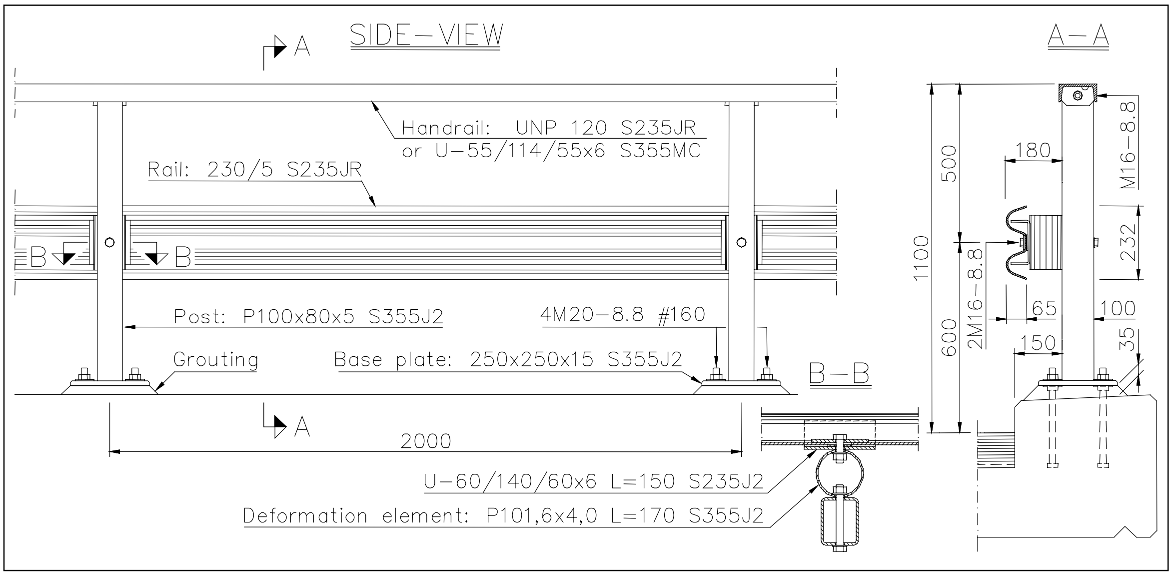

Figure 5.36 General drawing of the Finnra H1 vehicle parapet with 230/5 rail.

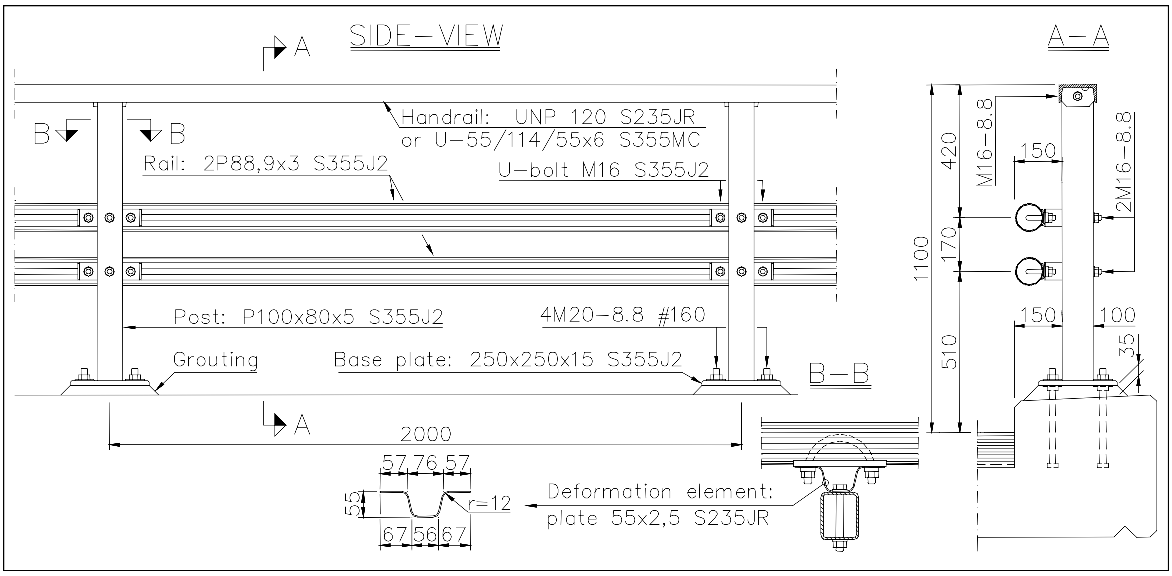

Figure 5.37 General drawing of the Finnra H1 vehicle parapet with 2-pipe rail.

5.4.2 Calculation analyses

Overview

The Finnra H1 vehicle parapet with the 230/5 rail was already tested as a modification of the High vehicle parapet (see Chapter 4.2.1). Its functioning in a heavy vehicle collision of level H1 was verified to conform to the European standard. Several posts nevertheless broke and failure was quite close. The results of the light vehicle test were more problematic. The THIV value was exceeded and it was decided to reduce the collapsing force of the deformation elements. Authorities decided that the reduction should be 20…25 per cent before the development work described in this thesis started. Thus, the thickness of the pipe deformation elements was changed from five to four millimetres.

Calculations and new tests on the Finnra H1 vehicle parapet were performed to study the functioning of the parapet under light vehicle impact when the 230/5 rail was replaced by the 2-pipe rail. No new heavy vehicle test was arranged. The previous test was approved by authorities as adequate proof of sufficient strength of the parapet against a heavy vehicle collision.

Rail and deformation elements

It was necessary to know the forces and moments acting on the structure during a heavy vehicle impact to estimate the required strength of the structural members. Data was received from the FE model of the vehicle restraint system built during the development of the Finnra H2 vehicle parapet (Fig. 5.38). The stresses from the analyses were a little too high due to the modified support reactions of the posts. By modelling the bases of the posts to correspond to the final situation, the model was kept reasonably simple, but the energy that would have gone into breaking the post was thus not taken into account.

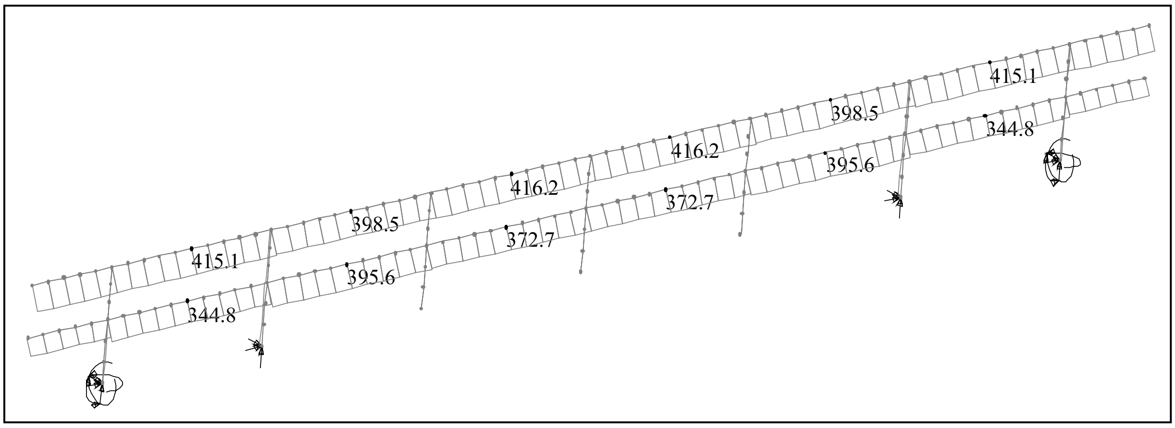

Figure 5.38 An example of the stresses obtained from the FE model of the vehicle restraint system: The tensile force of the Finnra H1 vehicle parapet near the impact area in Test TB 42 when the load resultant has reached the maximum value.

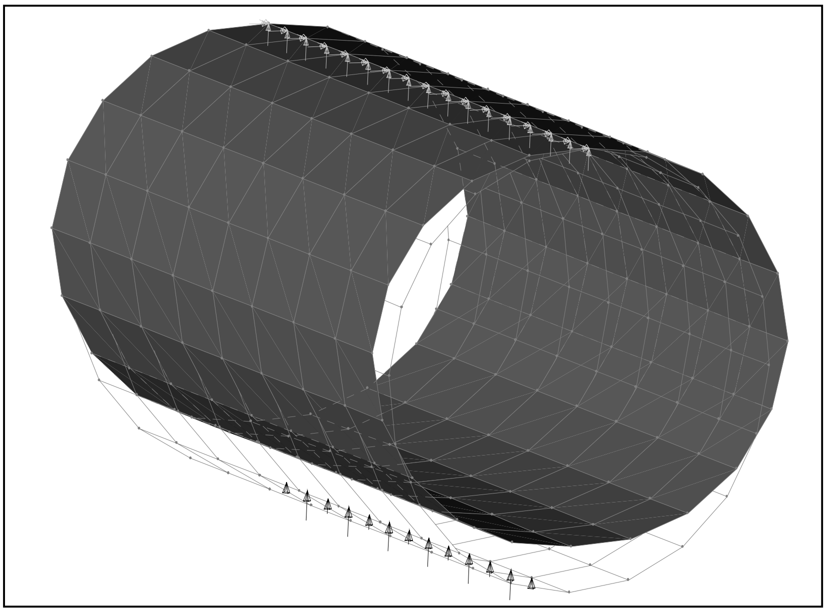

Figure 5.39 An FE model of the pipe deformation element with loading, support reactions and both undeformed mesh and shaded deformed mesh.

At first, the same 2-pipe rail as with the Finnra H2 vehicle parapet was chosen even though it was estimated that it might be a little too rigid. The 2P88.9×4 rail (S355J2) was chosen to keep the number of different members in standard vehicle parapets of Finnra as low as possible. Later, after the first test, the stiffness of the 2-pipe rail was decreased by replacing it with the one-millimetre thinner pipes.

The chosen three-millimetre wall thickness of the pipe is just enough, according to Finnish experiences, to prevent notable damages to the rail due to the small impacts from snow clearance equipment. The diameter of the pipes was not changed due to the favourable appearance of the developed 2-pipe rail. The combined moment of inertia and elastic moment capacity about the vertical direction of the chosen 2-pipe rail are 150 cm^4 and 11.9 kNm. If the reduction due the non-uniformity of the rail, presented in Chapter 5.2.2, is used, the moment of inertia is 131 cm^4.

Use of deformation elements between the posts and 2-pipe rails was obvious due to the high rigidity of the posts. First, the pipe deformation element used in the previous tests was analysed by the 3D shell element model involving geometric and material nonlinearities (Fig. 5.39) to find out its rigidity and the collapsing force (Fig. 5.40). Then, several different kinds of deformation elements were sketched of which the 45 mm wide (distance of the pipe rail from the posts) lipped omega section deformation element was chosen for both pipes of the rail.

The developed deformation element was adjusted to have an about 20 per cent lower collapsing force than the earlier used pipe deformation element. As an alternative, the plate thickness was reduced from three to two and half millimetres which created an even more flexible deformation element. An example of an FE model of the lipped omega section deformation element is shown in Figure 5.17 which presents a model of the deformation element of the Finnra H2 vehicle parapet with the 240/6 rail.

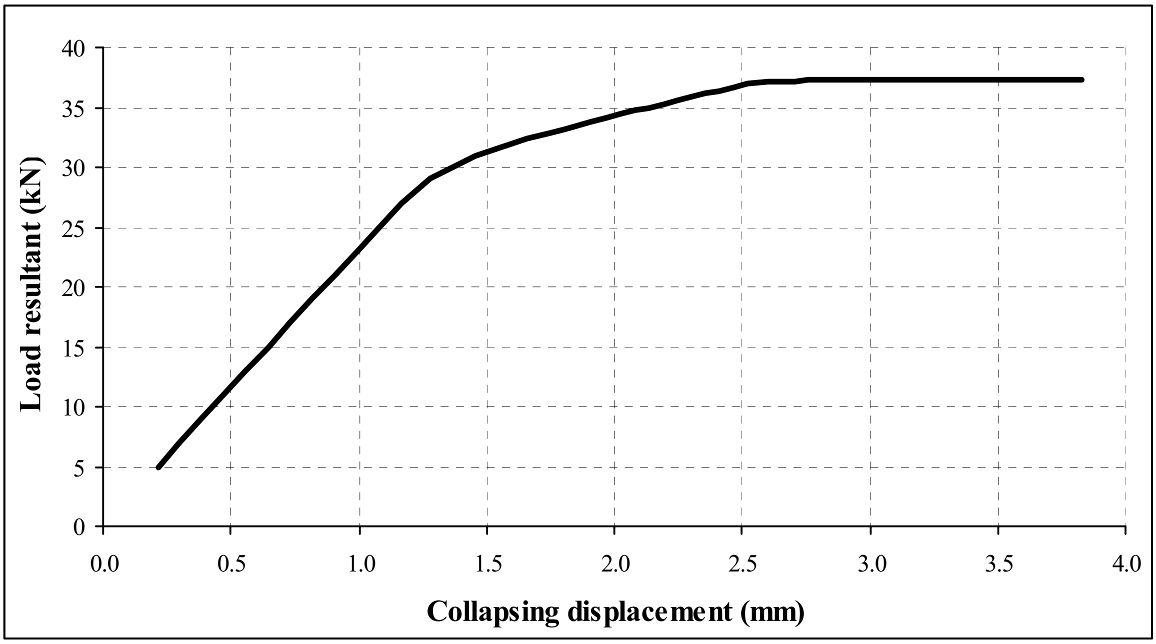

Figure 5.40 The load resultant value of the FE model of the P101.6×5 (S355) pipe deformation element computed as a function of collapsing displacement. The maximum value of the load, collapsing force, is 37.4 kN.

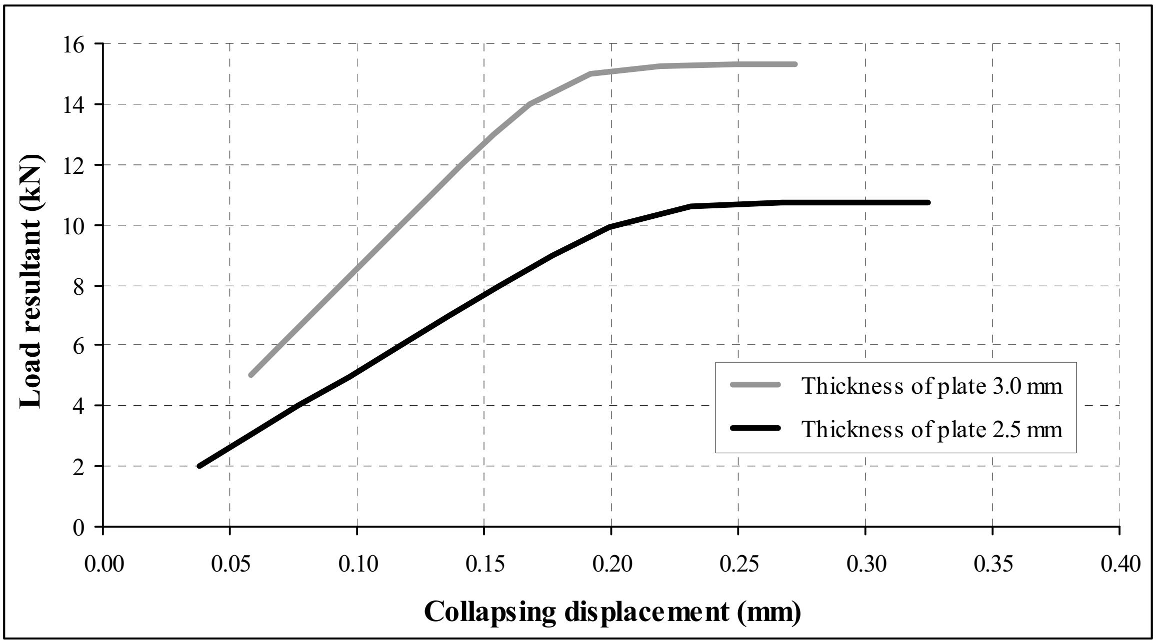

Figure 5.41 The load resultant values of the FE models of the single lipped omega section deformation elements (width 50 mm, width of plate 45 mm, steel S235, bending radius 12 mm) computed as a function of collapsing displacement. The maximum values of the loads, collapsing forces, are 30.6 kN and 21.2 kN for the deformation element pair (two elements per 2-pipe rail).

The functioning of the developed deformation elements with the 2-pipe rail of the Finnra H1 vehicle parapet under loading is shown in Figure 5.41. Computed collapsing forces are higher than the corresponding values of the deformation elements of the 240/6 rail. Thus, they have enough capacity to withstand the small impacts that, for instance, snow clearance equipment can cause.

To estimate the functioning of whole vehicle parapets with different rails and deformation elements, stretches of vehicle parapets were modelled by using 3D beam and joint elements involving geometric and material nonlinearities (Fig. 5.42). The deformation elements were modelled by using the joint elements and an elasto-plastic material model. The joints worked as an elastic spring with known stiffness until the force reached the yield value, the collapsing force of the deformation element, after which it was constant. The models were built on the developed and earlier light vehicle impact-tested structures, of which only Test 3, on the Finnra H2 vehicle parapet with a 2-pipe rail, satisfied all requirements of the standard.

The rigidity of the whole parapet was estimated by assigning an imaginary transversal point load on the rail. The functioning of the vehicle parapet was determined on basis of lateral displacement data of the rail (Fig. 5.43). The results showed that the parapet with pipe posts is a rigid structure that needs suitable adjusted deformation elements to decrease its rigidity. In Figure 5.43, the only structure with posts that are not pipes is the Finnra H2 vehicle parapet, which had the lowest rigidity with low load values. Because it was also the only structure without deformation elements, its rigidity was the highest with high load values. However, it was estimated that functioning in the beginning with low load values is more important, and the results indicated that the replacement of the 230/5 rail of the present standard frame by the stiffer 2-pipe rail made the parapet more rigid.

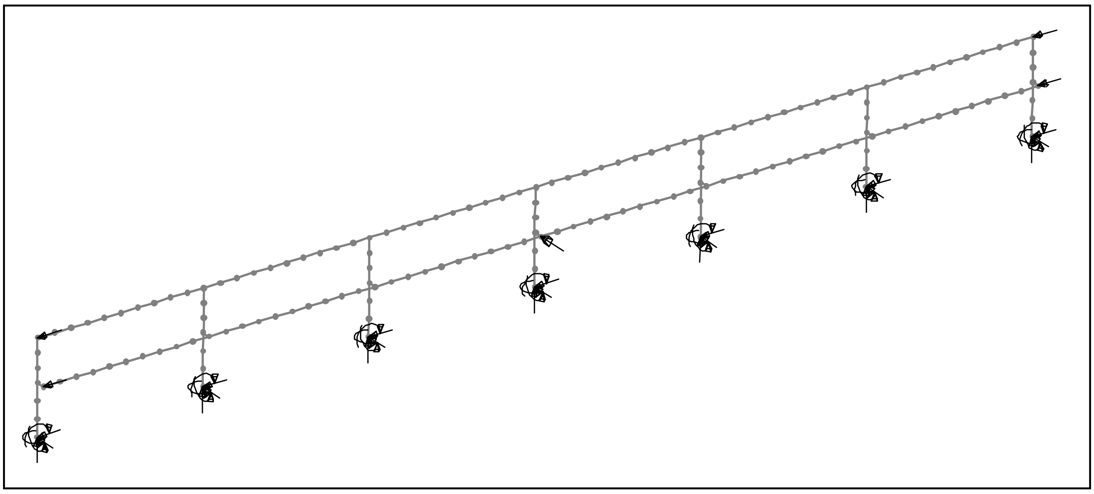

Figure 5.42 An FE model of a stretch of vehicle parapet with support reactions and imaginary point load on the rail (transversal force in the middle). The deformation elements between the rail and the posts are modelled as elasto-plastic joint elements.

The 20 per cent reduction in the collapsing force of the deformation element offset the increased rigidity of the parapet due to the stiffer rail, but to get less a rigid parapet it was estimated that the deformation elements need to be even more flexible. The deformation elements chosen for the first test were otherwise similar to the developed lipped omega section deformation element with 2.5 mm wall thickness, but they were made of 10 mm wider plate. Their functioning is an average of the functioning of the deformation elements presented in Figure 5.41. Thus, the curve in Figure 5.43 would intersect the curve of the Finnra H2 vehicle parapet at about where the slope of the latter curve changes.

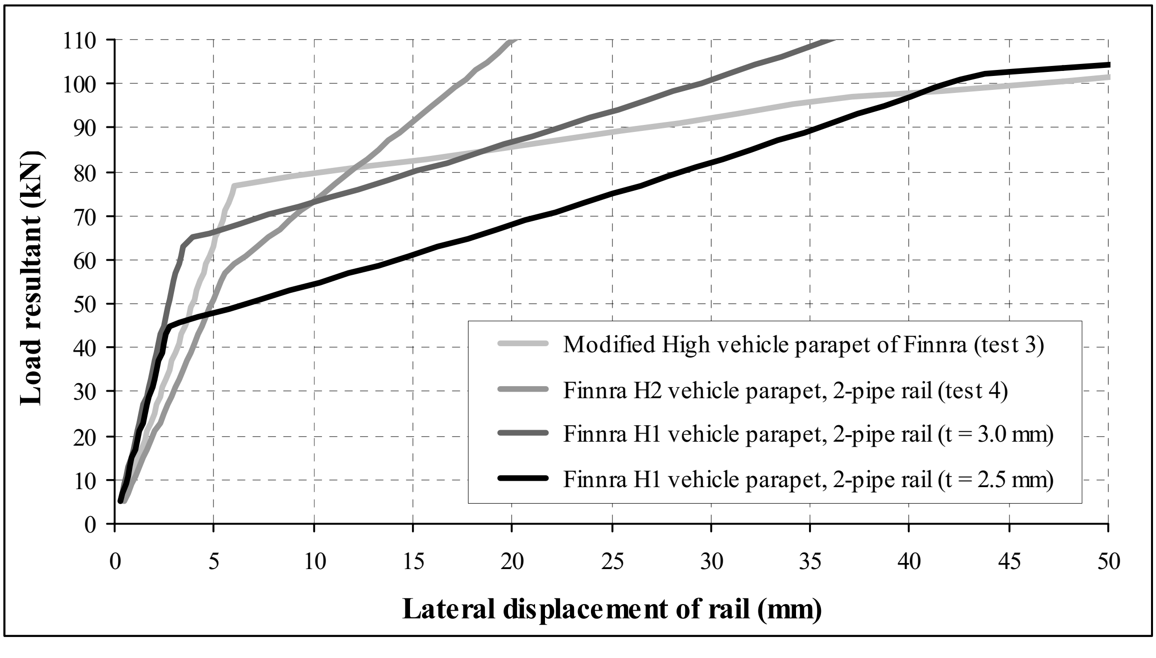

Figure 5.43 The load resultant values of the FE models of stretches of vehicle parapet with imaginary point load on the rail computed as a function of the lateral displacement of the rail. The 2-pipe rail of the Finnra H1 vehicle parapet is the same as with the Finnra H2 vehicle parapet. The properties of the deformation elements are presented in Figures 5.40 and 5.41.

It was estimated that the chosen parapet may still be slightly too rigid, but it was decided to test it to get an initial view about the functioning of the parapet. After the first, the rail was modified and deformation elements made almost as flexible as before the widening of the plate by increasing the width of the deformation elements by five millimetres.

5.4.3 Tests 6 and 7 (TB 11)

The Finnra H1 vehicle parapet with the 2-pipe rail was tested twice before the results were satisfactory. The first impact-tested structure had pipe rails with one-millimetre thicker walls and narrower deformation elements than the final structure. After Test 6 the pipes were changed to the thinner ones for Test 7 and the width of the lipped omega section increased from 50 mm to 55 mm.

Measurement data on the vehicle and the parapet are presented in Table 5.7. In Test 6 the impact speed was the maximum allowable while in Test 7 it was slightly under the minimum 100 km/h. In both tests the front right-hand side of the vehicle collided against the first post after the impact point with such a force that the right front wheel and the windscreen became detached (Figs. 5.44 and 5.45). In Test 6 also the radiator grille was detached and the footwell was strongly deformed and penetrated into the passenger compartment. During the impacts the cars changed their direction of travel and separated from the vehicle parapets being no longer in running condition.

Figure 5.44 Test 6: The impact and the damages to the test vehicle (Courtesy of HUT).

Figure 5.45 Test 7: The impact (Courtesy of HUT) and the damages to the test vehicle (Courtesy of A-Insinöörit Oy).

Table 5.7 Measurement data on vehicle and vehicle parapet.

Test	Weight [kg]	Speed [km/h]	Angle [°]	Impact point before post (m)	Length of contact (m)	Max. dynamic deflection (m) [1]	Max. static deflection (m) [1]
6	863	107	20	1.02	5.02	0.05	0.03
7	901	98	20	0.36	4.41	0.10	0.03

1) The maximum deflections presented here are deflections of the handrail although the rail had the biggest static deflections due to the collapse of the deformation elements. Dynamic deflections of rails were not measured.

The static collapsing displacements of the deformation elements were at a maximum 25 mm in Test 6 and 35 mm in Test 7 (Figs. 5.46 and 5.47). Deformation of the lipped omega section in Test 7 corresponded to design deformation while the first version did not work quite as wanted. In Test 6 the tensile force acting on the rail during the impact distorted the shape of the deformation elements before their collapsing.

Figure 5.46 Test 6: Deformation of the vehicle parapet after the impact (Courtesy of A-Insinöörit Oy) and functioning of the deformation element (Courtesy of HUT).

Figure 5.47 Test 7: Deformation of the vehicle parapet after the impact and functioning of the deformation element (Courtesy of A-Insinöörit Oy).

Table 5.8 The impact severity assessment indices.

Test	ASI	THIV [km/h]	PHD [g]
6	1.60	35	18
7	1.16	31	22

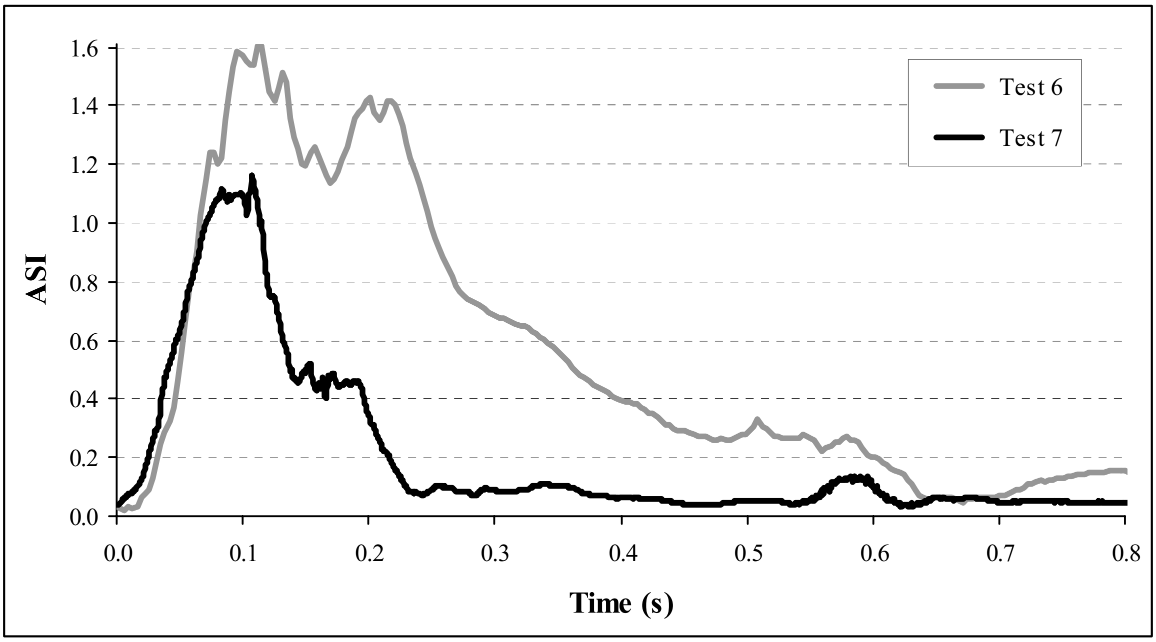

Figure 5.48 The acceleration severity index (ASI) values computed as a function of time.

The tyre marks were not as visible after the impact due to the low edge beam as they were in the test on the Finnra H2 vehicle parapets. Impact severity assessment indices computed from the test results are presented in Table 5.8. Variations in ASI values during the impacts are shown in Figure 5.48. In Test 6 the ASI and THIV values exceeded requirements of 1.4 and 33 km/h. The results of Test 7 were considerably better than in Test 6, but the PHD went slightly over the maximum value 20 g due to the quicker change of direction of travel of the vehicle during the first part of the collision.

The calculation of PHD starts where THIV ends, which is the moment when the head of the occupant hits against the notional impact surface inside the vehicle. The earlier the head hits against the impact surface, the higher is the PHD value normally. The transversal distance of the impact surface is half of its longitudinal distance. If the vehicle turns quickly, the head moves rapidly transversally and hits the impact surface earlier than if it would move more longitudinally.

5.4.4 Conclusions

The vehicle parapet otherwise similar to the one used in Test 3 (230/5 rail), but with thinner pipe deformation elements, and the one used in Test 7 (2-pipe rail) were chosen as the final structures. They were approved for use as containment level H1 structures in Finland by authorities. The parapets did not, however, quite fulfil all the requirements of the standard. The occupant impact severity was slightly too high in both Tests 3 and 7. Although in Test 7 the difference between the results of the tests and requirements was quite small.

Also, the functioning of the vehicle parapet equipped with the 2-pipe rail in the heavy vehicle test is not quite certain, because it was not tested. Most likely it would work well due to the stiffer rail which distributes the load to the posts more evenly than the acceptably tested open section rail, but the stiffer rail may also trip the vehicle too heavily against the handrail.

The structure with the 230/5 rail used in Test 3 was not tested after the modification made to the deformation elements. According to the experiences received from several light vehicle tests of the Finnra H2 vehicle parapet with the 240/6 rail, the uniform open section rails used with Finnish standard vehicle parapets will probably not alone adequately prevent the heavy impact of a light vehicle against the post, when their height from the road surface is the used one. Thus, the modification made to the pipe deformation elements of the 230/5 rail will most likely not decrease occupant impact severity enough.

The vehicle parapets conforms nevertheless adequately to containment level H1 structures, considering that the Finnra H1 vehicle parapets are going to be used outside the main roads and mainly in rehabilitation and repair of bridges, while the requirements of the European standard concern only new building. They are not going to be common structures, because their reasonable use requires that the existing parapet and the concrete edge beam are in good enough condition. They are also wide structures, and thus quite expensive, if the required widening of the bridge deck is taken into account.

The tests were conducted on parapets on the low edge beam, while the high edge beam, which is nowadays normally used, might have given less severe results. Thus the test arrangements resulted in a safety margin which also partly justifies giving level H1 approval to the vehicle parapet.

6 RESULTS

6.1 Functioning of used analysis method

The used analysis method worked as intended. It allowed developing a vehicle parapet which conforms to containment level H2 of Standard EN 1317, at least when using the 2-pipe rail. Final approval by authorities of the Finnra H2 vehicle parapet with the 240/6 rail is still pending. In the first stage calculation analyses based on previous Finnish and Swedish full-scale impact tests were used to design the new parapet frames approximately. Then, the vehicle parapets were impact-tested and the test results were used in further development.

Some of the developed structures did not quite fulfil all the requirements of the standard, but it would have been possible to continue the development process by using the same method and finally attain structures that would satisfy the standard. In the case of the Finnra H1 vehicle parapets, development was stopped by the authorities when the satisfactory safety performance was reached. This was done because those parapets are designed to be used mainly in rehabilitation and repair projects while the standard concerns only new building. Consequently, the hope was to make as few changes as possible to the frame which is based on the present standard vehicle parapet.

6.2 Approved vehicle parapets

6.2.1 Direction

The publication “Vehicle parapets” (Finnish Road Administration 2002) will be released as a result of the development project; it will be also available on the Internet (www.tiehallinto.fi/sillat/). A printed version can be ordered from Finnra. The publication consists of a design manual and the quality requirements for vehicle parapets to be used in Finland as well as the drawings of new Finnish standard vehicle parapets. The general demands for vehicle parapets used on road bridges administered by Finnra are defined in the safety policy presented in the next chapter, which is a translated quotation from the final draft version of the publication. Unlike Standard EN 1317, the safety policy also specifies the requirements for vehicle parapets of existing bridges.

6.2.2 Safety policy

Vehicle parapets conforming to containment level H2 of Standard EN 1317 are used on bridges on main roads in new building. H1 is an adequate containment level for the rest of the road network. Dynamic deflection (D) of vehicle parapets may not exceed 1.0 m.

Vehicle parapets are replaced during rehabilitation or repair work if the parapets or the edge beams of the bridge are deteriorated, or if the bridge is on a main road and the vehicle parapets are of lower containment level than H2. When replacing the vehicle parapets of existing bridges, the containment level requirements of new building are followed. If the vehicle parapets are only repaired, they must be equipped to meet at least containment level H1.

An exception to containment level requirements form bridges, defined by a representative of the authorities, that require special protection — should a vehicle fall off it, a catastrophe would likely ensure. An example is a bridge that crosses a railway yard. In such cases a vehicle parapet of containment level H3, concrete vehicle parapets of Finnra or a corresponding concrete vehicle parapet is used. The above-mentioned concrete vehicle parapets can also be used instead of containment level H1 and H2 structures, if noise protection requirements so demand.

6.2.3 Vehicle parapets conforming to requirements

Vehicle parapets used on road bridges administered by Finnra do not have to be standard Finnra structures. Also other vehicle parapets that conform to Standard EN 1317 and the quality requirements of the publication “Vehicle parapets” can be used. Vehicle parapets used on road bridges administered by someone other than Finnra (e.g. municipalities) do not have to fulfil the requirements of the publication “Vehicle parapets”, unless so defined. However, in new building, if public funding is involved, the chosen vehicle parapet must conform to Standard EN 1317.

The containment level requirements of the safety policy of Finnra lead to a situation where mainly H2 level structures are used as vehicle parapets. Level H1 vehicle parapets can be used outside the main roads, but the Finnra H1 vehicle parapets are about as expensive to use as level H2 structures, if the widening of the bridge deck is taken into account, and aesthetically less pleasing. Level H1 vehicle parapets shall mainly be used in rehabilitation and repair of bridges, where the condition of the parapet and the concrete edge beam is such that it is reasonable to equip the present standard vehicle parapet meet the requirements of level H1. Such cases can normally be found only in northern Finland were salting of roads, which damages the edge beams of the bridge deck, is used less.

The concrete vehicle parapets of Finnra whose drawings R15/DK 10…12 are available on the Internet (www.tiehallinto.fi/sillat/tyyppipiirustukset/sillanosat/luettelo.htm), or other concrete wall vehicle parapets, that fulfil the requirements given in the publication “Vehicle parapets”, can be used instead of level H3 structures, which are rare at the moment. Such concrete parapets have enough capacity against a heavy vehicle collision, but occupant impact severity is most likely slightly higher than the current version of the standard allows. They are, however, accepted due to the shortage of level H3 structures.

6.2.4 New Finnish standard vehicle parapets

The frames of the new developed Finnish standard vehicle parapets are presented in Chapters 5.2.1, 5.3.1 and 5.4.1. More precise drawings including the equipment whose development is not dealt with in this thesis, are provided in Appendices 1 and 2. These standard drawings shall also be available on the Internet (www.tiehallinto.fi/sillat/tyyppipiirustukset/sillanosat/luettelo.htm). Aesthetic requirements as well as the requirements of fabrication and installation have been taken into account in the development of the new vehicle parapets. During the project experimental building of the developed vehicle parapets was done as part of actual bridge projects (Fig. 6.1), conversations with manufacturers were held and drawings were distributed for comments.

Figure 6.1 Experimental building of the developed Finnra H2 vehicle parapet with the 2-pipe rail and mesh infill on the Lemissaari flyover in Helsinki, Finland (2001) (Courtesy of Finnra).

The frame of the vehicle parapet does not need any additional equipment to reduce the size of the openings if pedestrian traffic on the bridge is prohibited with a traffic sign, as is the case on motorways. If it is not prohibited, and there is no pedestrian and bicycle way beside the parapet, at least middle rails over and above the rail are needed. When there is a pedestrian and bicycle way beside the parapet, a rail infill with vertical bars has normally been used. According to new requirements, a rail infill is not allowed in new building anymore because of its unopenness, which can even be a safety risk, if there is an access ramp just after a bridge. A mesh infill is used instead which is also needed due to snow clearance when the road under the bridge needs to be protected from ploughed snow.

6.3 Accident cost-effect analysis

The results of a cost-effect analysis of increased safety of vehicle parapets are presented here. The analysis is not totally exact but gives an idea of the cost-effect. The cost calculation for an investment made in one year has been extended over 35 years which is estimated by Finnra to be the period after which the bridges must be rehabilitated.

The additional cost per linear metre of parapet, exclusive of value added tax, due to building the new standard vehicle parapets, instead of the present standard vehicle parapet, was estimated to be about 40 EUR. The estimation was based on the assumption that new parapets are mainly the Finnra H2 vehicle parapets with the 2-pipe rail since the Finnra H2 vehicle parapets with the 240/6 rail, which is a more expensive structure, are used only on a small scale. The calculated cost was a little higher than the price difference between the Finnra H2 vehicle parapet with the 2-pipe rail and the present standard vehicle parapet.

The price difference estimation of the new and present vehicle parapets is on the safe side because the Finnra H1 vehicle parapets, which are cheaper, were not taken into account, although, at least in the beginning, they may be used in some projects. The annual expense due to the implementation of the new standard vehicle parapets was calculated to be about 336,000 EUR, because the total amount of constructed vehicle parapet per year is about 8.4 km.

By assuming that new vehicle parapets halve the number of injuries, compared to the present standard vehicle parapet, in collisions where the terminal pier is not the accident factor, the number of injuries can be estimated to fall by 0.042 per year, if the new standard structures are used in the bridges built in a year. The corresponding value of the saved accident costs was calculated to be a little over 6,700 EUR. The calculations were based on the accident data of the 1990’s and on the fact that the number of bridges with vehicle parapets constructed per year represents 0.7 per cent of the total amount of bridges carrying road traffic.

If the saved accident costs over 35 years are discounted to the value of the investment year, the total saved amount comes to 342,000 EUR assuming an annual inflation rate of 2 per cent. Thus, the cost saving is about the same as the investment. The made cost calculation is, however, quite sensitive to changes in the assumptions. For example, if the new vehicle parapets lower injuries by one third instead of by half, the total saved amount would be 229,000 EUR. The difference is nevertheless quite small because the overall sums are small.

The investment per year due to the implementation of the new standard vehicle parapet is quite small for society, and invested money will be about recovered through saved accident costs. The essential thing is that the number of injuries will fall as will the high risk of severe consequences of public transport vehicle accidents: one major accident would totally upset the cost-effect analysis.

7 CONCLUSIONS

7.1 On developed vehicle parapets

The new Finnish standard vehicle parapet types, which conform adequately to Standard EN 1317, were successfully developed by the chosen method. The vehicle parapets were developed for national use, but the structures conforming to the standard could, and may in the future, be used also in other countries.

The Finnra H2 vehicle parapet fulfilled the requirements of the standard, at least when equipped with the 2-pipe rail. Final approval by authorities of the Finnra H2 vehicle parapet with the 240/6 rail is still pending, because the last full-scale light vehicle test gave contradictory results, while run computer simulations indicate that the structure fulfils the requirements of the standard. The Finnra H1 vehicle parapets did not quite meet all the requirements of Standard EN 1317 which concerns new building. They were, however, approved by the authorities for use outside the main roads on a limited scale because they are modifications of the present standard vehicle parapet, and, instead of replacing an existing parapet, it is sometimes better to modify it to be more impact safe in connection with the rehabilitation or repair of bridges.

The functioning of the new Finnish standard vehicle parapets were impact-tested only with the low or high edge beam and without the equipment (middle rails and mesh infill). Yet, the structures were approved by the authorities for use with or without the equipment and both on high and low edge beams. The Finnra H1 vehicle parapets, which were tested on the low edge beam, were approved for use also on the high edge beam because a collision against the structure on a low edge beam was estimated to be more severe than a collision against the structure on a high edge beam. The Finnra H2 vehicle parapets, which were tested on a high edge beam, were approved for use also on a low edge beam because low edge beams are only rarely used nowadays and the safe functioning of the structures on it in case of a heavy vehicle impact, where the risk of severe consequences is higher than with a light vehicle impact, could be analysed with the reasonable certainty.

Only the frames of the developed vehicle parapets were impact-tested because there are no specifications for the equipment in the standard and their effect on the functioning of the vehicle parapets was not considered significant. The last presumption is most probably true in the case of a heavy vehicle impact. At least, the equipment do not lower the capacity of the structure, but in the case of a light vehicle impact there may occur some problems with occupant impact severity if the functioning of the parapet is such that the front wheel, which is detached by a heavy impact against the post, can freely separate from the vehicle. With the equipment in place the situation can be such that the front wheel cannot separate from the vehicle, and may, for instance, penetrate into the vehicle and affect the impact severity assessment indices. This phenomenon needs to be studied more.

The diagonal anchoring of the handrail, where a tension force develops during the impact, to the edge beam is used on both sides of an expansion joint of a bridge to avoid a significant reduction in the structural capacity of the vehicle parapet due to the big gap in the handrail. The diagonal anchor of the handrail is a structural member that has not been used in Finland earlier; initially it was designed for use with vehicle parapets of containment level H2 on big bridges with a free motion over ± 50 mm. However, it is obviously also needed in other vehicle parapets and bridges with less free motion. With the

Swedish standard vehicle parapet, a similar structure is required already if the free motion is over ± 15 mm.

The current version of the European standard does not contain exact requirements for expansion joints, but the effect of their free motion on the functioning of the vehicle parapet needs to be taken into account. The Finnish vehicle parapets have been impact-tested with expansion joints with corresponding small free motion as normal splices, installation and expansion joints, of horizontal members. In small bridges, the expansion joints have little free motion and do not cause problems. In bigger bridges there is more free motion leading to a distinct reduction in the parapets structural capacity — especially near the expansion joints.

It is hard to estimate exactly when the handrail should anchored without more detailed study of the problem. The limit used in Sweden seems quite good. In Finland the limit is quite high, but the idea is that diagonal anchor of the handrail should be used in the beginning in experimental building. In the future the structure may be used with all different vehicle parapets and also with smaller free motion. More exact study of the problem may become topical when the transitions, the connections between safety barriers on roads and bridges, come under research, which will probably constitute the next phase of the development of safety barriers in Finland.

7.2 On used analysis method

7.2.1 Overview

The successfully used analysis method in the development of new Finnish standard vehicle parapets was a combination of calculation analyses, full-scale impact tests and experiences from the process, that is, an understanding of the impact phenomena and the effect of different structural members of the vehicle parapet on them.

7.2.2 Full-scale impact tests

The heights of the centre of gravity of the buses used in similar impact tests on Finnish and Swedish vehicle parapets were different. In the standard, requirements for centre of gravity height are given only for light vehicles and for the ballast of the heavy vehicle. So, in the case of a heavy vehicle impact the requirements of the standard can be fulfilled whatever the centre of gravity height of the vehicle has. This phenomenon can be significant especially with buses because there are low-entry buses with a low centre of gravity. The lower the centre of gravity is, the less severe the impact of the heavy vehicle. Thus the limits for centre of gravity height of all vehicles should be defined in the standard.

According to the standard, the impact point shall be chosen to represent the worst testing conditions of the safety barrier, and shall include any sensitive feature of the design. The location of the impact point, with respect to the distance to the next post after the impact point, is an important factor concerning occupant impact severity in the light vehicle test. Estimating it for the test so that the most severe condition is created is a challenging task. The location of the impact point should be such that the vehicle hits as hard against the post as possible.

In the light vehicle tests on new Finnish standard vehicle parapets, several distances between the impact point and the post were used. It was a consequence of different designed locations of impact points and tolerances between actual and the designed points. In the first stage, the impacts were arranged so that the designed impact point was at about midway between the two posts while later it was near the post. The only structure that had several different impact points in the light vehicle tests was the Finnra H2 vehicle parapet with the 240/6 rail. The final full-scale impact-tested modification of the structure was computer simulated using two different impact points.

Based on the experiences from the development process of the new Finnish standard vehicle parapet, the distance of the impact point before the post should be about half of the post spacing. The stiffer the rail, the bigger distance is required to make sure that the rail deforms adequately before the vehicle hits the post. Yet, it is not good to have the impact point too close to the post before the impact point, because then its deformations (incl. possible deformation element) absorb too much impact energy before the main crash against the next post.

The conclusion concerning the impact point in the light vehicle test is preliminary, because the data from the tests does not enable a more exact conclusion. The subject should be studied more and the results should be put to use in the development of the standard. As more was learned about the impact phenomenon during the development of new Finnish standard vehicle parapets, it later become obvious that more severe impact point locations might have been used is some arranged light vehicle tests. The requirement of the current version of the standard concerning the impact point was nevertheless estimated to fulfil adequately.

The common European calibration test on different testing laboratories certified the suspicions that the accuracy of measurement in the full-scale tests is in some cases already too sensitive. This was not the case with Finnish tests although there was a slight improvement in accuracy of measurement after Test 6. There are testing laboratories that use transducers of several times higher frequency than the frequency needed to measure the occupant’s movements. The impact severity assessment indices computed from that kind of test data give too severe a picture of the impact, because the data include also vibratory actions. Therefore, requirements for the accuracy of measurement should be created and added to the standard.

At the same time, the allowable values of impact severity assessment indices should be reconsidered. There has been discussion about having in the future a level C, where no requirement for the acceleration severity index value exists. A new level is needed because concrete vehicle restraint systems no longer fulfil the requirements of level B, which was originally developed for them. However, this alone does not update the standard to correspond to the present state of the accuracy of measurement. The limits of other impact severity assessment indices should also be re-estimated, and instead of new level with unlimited ASI value, the values of the existing levels should rather be reconsider.

7.2.3 Calculation analyses

Because the aim was to keep cost at a reasonable level, the used FE analyses were case-specific and quite simplified although there were more reality-accurate but expensive FE systems on the market, like the Nordic simulation application. During the process the price of the Nordic simulation application fell remarkably which is why it was tested to get experience from it for possible future use. The application could be used, for instance, in studying the effects of edge beam height, the equipment of the vehicle parapets, the diagonal anchor of the handrail and the location of the impact point in more detail.

The experiences from using the more reality-accurate FE system were promising. The system made pre-analysis of occupant impact severity easier. Thus, the introduction of such a system seems suitable further development of the analysis method used here. The new FE system would not change the basic idea of the method. Idea generation and calculation analyses based on experiences would still need to be done as well as full-scale impact tests. After all, FE analyses are only tools. They do not develop the structures by themselves.

The next logical phase in improving computer simulation would be the development of Standard EN 1317 so that simulations could be used without verifying the results each time with a full-scale impact test. The current version of the standard does not include any specification about computer simulation, but it is estimated that the next revision of the standard may contain a list of cases where simulations can be used with a simple modification of the full-scale impact-tested safety barrier. This is the first step toward better utilisation of computer simulations, but it would be more advantageous to develop the standard so that simulations could be used along with full-scale impact tests.

Partial replacement of full-scale tests with computer simulations could be done, for instance, by requiring that only some simulations need to be full-scale impact-tested and the results of the simulations and the tests be compared. Small differences in the results would be the requirement for official approval of an application by some acceptance organisation. A better system for verifying the reality of computer simulations would be using benchmark problems written in the standard with certain requirements for the results of the simulations. The number of these problems, based on full-scale impact tests, should be such that they adequately describe the different impact situations. Thus, computer simulation applications could be approved for use, after their functioning has been satisfactorily tested. Development of benchmark problems could finally even lead to total replacement of full-scale tests.

Even though computer simulations offer many possibilities, the progress should be careful. When the FE system becomes more reality accurate, the significance of precise modelling increases even as concerns small details of the vehicles and vehicle restraint systems. With simplified FE models, like the ones used in this thesis, many details can be left unmodelled. It is more important to understand the functioning of the systems, so that simplified models can be created and the results evaluated. With more complex models, the results are more exact and thus results evaluation offers less possibilities. This increases the importance of precise modelling. In an extreme situation this means that, for instance, even a small mistake in the modelling of wheel suspension can lead to totally different results than would have been yielded by a full-scale impact test.

7.3 On accident cost-effect analysis

According to the accident cost-effect analysis, the savings due to a decreasing number of injuries in collisions against vehicle parapets is about the same as the need to invest in the implementation of new safer but more expensive standard vehicle parapets. The analysis involved many approximations and, thus, gives only an idea of the cost-effect. For more precise analysis, statistics on the effects of the use of impact-safer standard vehicle parapets is needed over a reasonable time. Because the total amount of constructed parapets per year is quite small and existing vehicle parapets are not going to be replaced except in normal rehabilitation and repair projects, it will take a long time before there will be more exact information about the reduction in injuries.

According to the accident analysis performed, if the new standard vehicle parapets are used in the bridges built in a year, only about two injuries are avoided in the first ten years, but after twenty years the figure is already about one injury per year and so on. Thus, the time of the possible reanalysis of the cost-effect would be, at the earliest, after the first decade. However, the reanalysis does not necessarily have to be done because the costs of increasing the safety of vehicle parapets are quite small and in any case beneficial: the number of injuries will decrease and the high risk of the severe consequences, when public transport vehicles collide against the vehicle parapet, falls. The latter accident type did not appear in the analysed data. If it had been there, the calculated savings would have been several times higher.

7.4 On Standard EN 1317

The development aspects of the standard, based on the experiences from the development process of new Finnish standard vehicle parapets, are dealt within Chapters 7.1 and 7.2. The development of the European standard has been taken up, because the environment is changing. Examples of that are the implementation of computer simulations and development of the accuracy of measurement in full-scale impact tests. In any case, the development of the standard should be continuous process because it deals with problems for which comprehensive specifications are difficult to define. The adequacy of the acceptance tests of the standard in guiding the development of the safety of vehicle restraint systems should be followed by a study of the structures successfully developed to conform to the standard. It is recommended in Standard EN 1317-1:1998 that it be reviewed within a period of five years or following the completion of a proposed set of impact validation tests.

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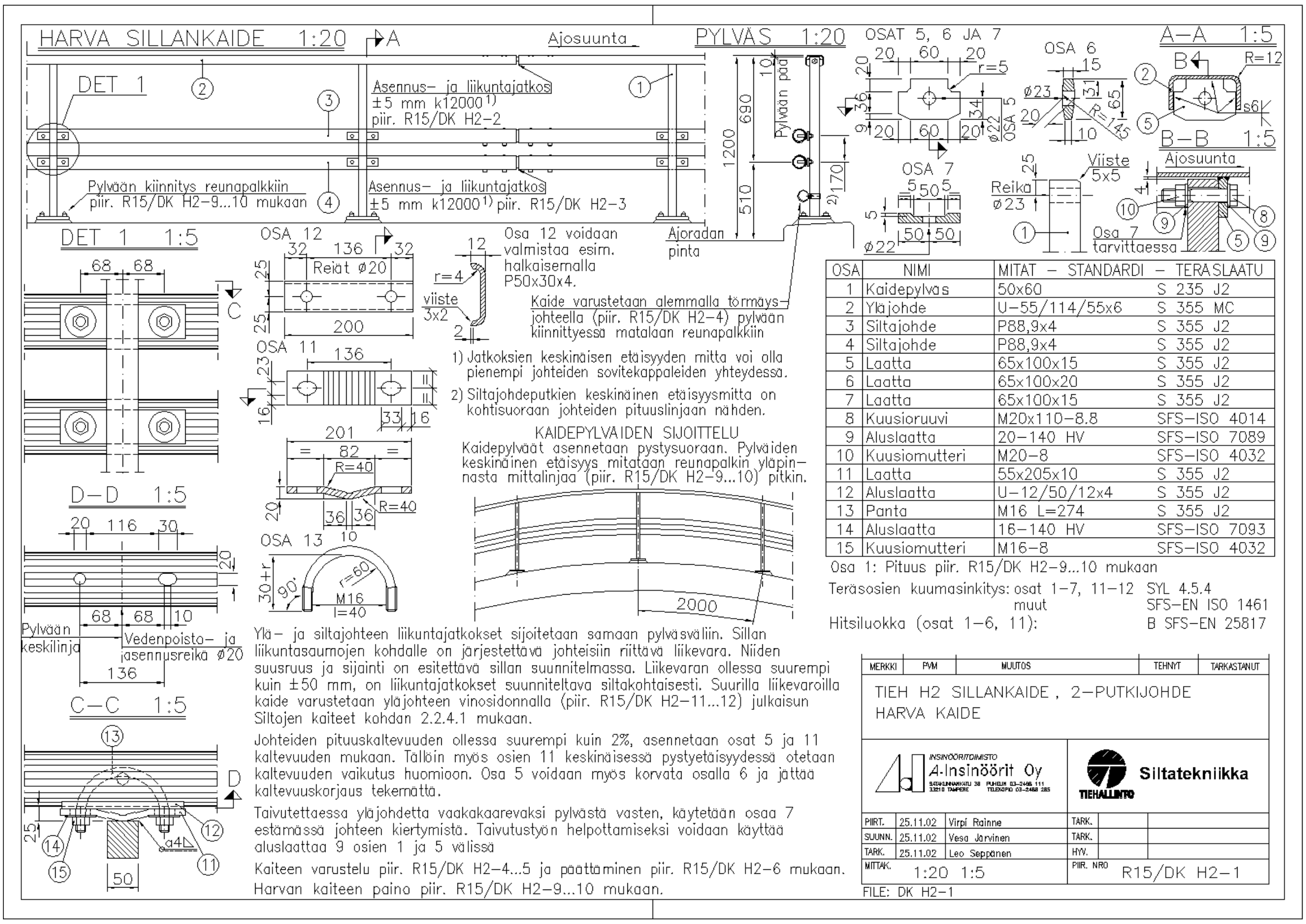
Appendix 1 Standard drawings of the Finnra H2 vehicle parapets:

- R15/DK H2-1 Frame, 2-pipe rail
- R15/DK H2-2 Bolted expansion joint of handrail
- R15/DK H2-3 Bolted expansion joint of pipes
- R15/DK H2-4 Middle rails and lower rail
- R15/DK H2-5 Mesh infill
- R15/DK H2-6 Transition, 2-pipe rail
- R15/DK H2-7 Bolted end treatment joint of handrail
- R15/DK H2-8 Joint between rails on bridge and road, 2-pipe rail
- R15/DK H2-9 Bolt fixing to high edge beam, 2-pipe rail
- R15/DK H2-10 Bolt fixing to low edge beam, 2-pipe rail
- R15/DK H2-11 Diagonal anchor of handrail, frame
- R15/DK H2-12 Diagonal anchor of handrail, details
- R15/DK H2-13 Frame, 240/6 rail
- R15/DK H2-14 Bolted expansion joint of rails, 240/6 rail
- R15/DK H2-15 Transition, 240/6 rail
- R15/DK H2-16 Bolt fixing to high edge beam, 240/6 rail
- R15/DK H2-17 Bolt fixing to low edge beam, 240/6 rail

Additional drawings (used with the experimental building):

- R15/DK H2-L1 Hole fixing to high edge beam
- R15/DK H2-L2 Hole fixing to low edge beam



Osa 12 voidaan valmistaa esim. halkaisemalla P50x30x4.

Kaide varustetaan alemmalla törmäysjohteella (piir. R15/DK H2-4) pylvään kiinnittyessä matalaan reunapalkkiin

1) Jatkoksien keskinäisen etäisyyden mitta voi olla pienempi johteiden sovitekappaleiden yhteydessä.

2) Siltajohdeputkien keskinäinen etäisyysmitta on kohtisuoraan johteiden pituuslinjaan nähden.

KAIDEPYLVÄIDEN SIJOITTELU

Kaidepylväät asennetaan pystysuoraan. Pylväiden keskinäinen etäisyys mitataan reunapalkin yläpinnasta mittalinjaa (piir. R15/DK H2-9...10) pitkin.

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
1	Kaidepylväs	50x60	S 235 J2
2	Yläjohde	U-55/114/55x6	S 355 MC
3	Siltajohde	P88,9x4	S 355 J2
4	Siltajohde	P88,9x4	S 355 J2
5	Laatta	65x100x15	S 355 J2
6	Laatta	65x100x20	S 355 J2
7	Laatta	65x100x15	S 355 J2
8	Kuusioruuvi	M20x110-8.8	SFS-ISO 4014
9	Aluslaatta	20-140 HV	SFS-ISO 7089
10	Kuusiomutteri	M20-8	SFS-ISO 4032
11	Laatta	55x205x10	S 355 J2
12	Aluslaatta	U-12/50/12x4	S 355 J2
13	Panta	M16 L=274	S 355 J2
14	Aluslaatta	16-140 HV	SFS-ISO 7093
15	Kuusiomutteri	M16-8	SFS-ISO 4032

Osa 1: Pituus piir. R15/DK H2-9...10 mukaan

Teräsosien kuumasinkitys: osat 1–7, 11–12 SYL 4.5.4; muut SFS-EN ISO 1461

Hitsiluokka (osat 1–6, 11): B SFS-EN 25817

Ylä- ja siltajohteen liikuntajatkokset sijoitetaan samaan pylväsväliin. Sillan liikuntasaumojen kohdalle on järjestettävä johteisiin riittävä liikevara. Niiden suusruus ja sijainti on esitettävä sillan suunnitelmassa. Liikevaran ollessa suurempi kuin ±50 mm, on liikuntajatkokset suunniteltava siltakohtaisesti. Suurilla liikevaroilla kaide varustetaan yläjohteen vinosidonnalla (piir. R15/DK H2-11...12) julkaisun Siltojen kaiteet kohdan 2.2.4.1 mukaan.

Johteiden pituuskaltevuuden ollessa suurempi kuin 2%, asennetaan osat 5 ja 11 kaltevuuden mukaan. Tällöin myös osien 11 keskinäisessä pystyetäisyydessä otetaan kaltevuuden vaikutus huomioon. Osa 5 voidaan myös korvata osalla 6 ja jättää kaltevuuskorjaus tekemättä.

Taivutettaessa yläjohdetta vaakakaarevaksi pylvästä vasten, käytetään osaa 7 estämässä johteen kiertymistä. Taivutustyön helpottamiseksi voidaan käyttää aluslaattaa 9 osien 1 ja 5 välissä

Kaiteen varustelu piir. R15/DK H2-4...5 ja päättäminen piir. R15/DK H2-6 mukaan.
Harvan kaiteen paino piir. R15/DK H2-9...10 mukaan.

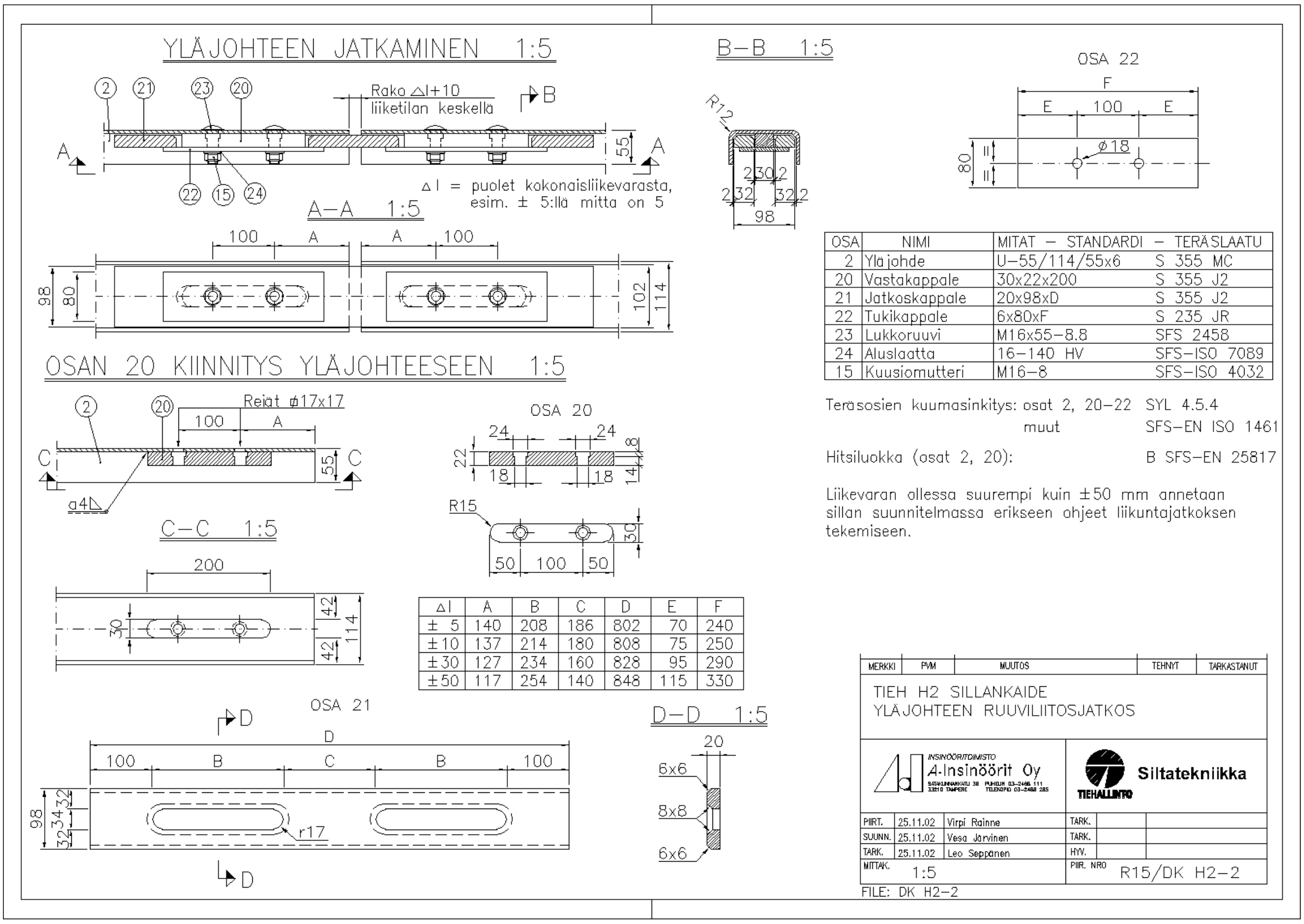
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

TIEH H2 SILLANKAIDE , 2-PUTKIJOHDE
HARVA KAIDE

Insinööritoimisto A-Insinöörit Oy — Siltatekniikka — Tiehallinto

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:20 1:5		PIIR. NRO	R15/DK H2-1

FILE: DK H2-1



△l	A	B	C	D	E	F
± 5	140	208	186	802	70	240
±10	137	214	180	808	75	250
±30	127	234	160	828	95	290
±50	117	254	140	848	115	330

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
2	Yläjohde	U-55/114/55x6	S 355 MC
20	Vastakappale	30x22x200	S 355 J2
21	Jatkoskappale	20x98xD	S 355 J2
22	Tukikappale	6x80xF	S 235 JR
23	Lukkoruuvi	M16x55-8.8	SFS 2458
24	Aluslaatta	16-140 HV	SFS-ISO 7089
15	Kuusiomutteri	M16-8	SFS-ISO 4032

Teräsosien kuumasinkitys: osat 2, 20–22 SYL 4.5.4; muut SFS-EN ISO 1461

Hitsiluokka (osat 2, 20): B SFS-EN 25817

Liikevaran ollessa suurempi kuin ±50 mm annetaan sillan suunnitelmassa erikseen ohjeet liikuntajatkoksen tekemiseen.

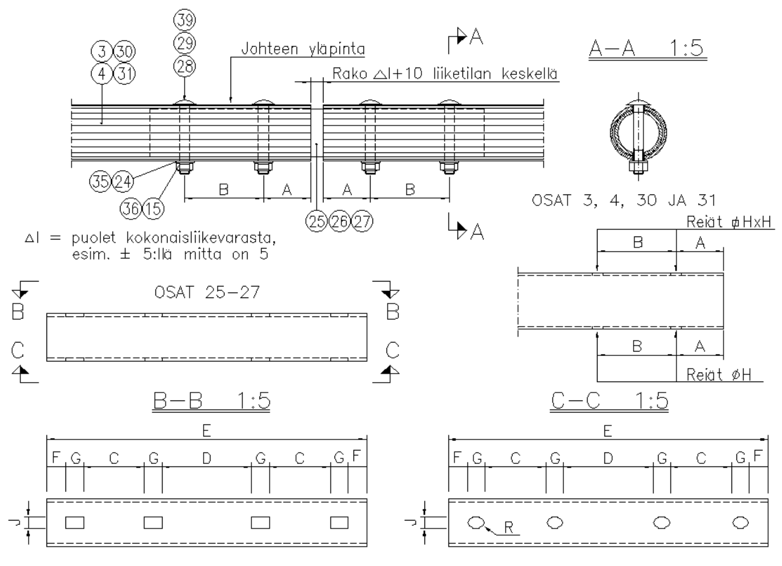
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

TIEH H2 SILLANKAIDE
YLÄJOHTEEN RUUVILIITOSJATKOS

Insinööritoimisto A-Insinöörit Oy — Siltatekniikka — Tiehallinto

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:5		PIIR. NRO	R15/DK H2-2

FILE: DK H2-2



OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
SILTAJOHTEEN JATKAMINEN			
3	Siltajohde	P88,9x4	S 355 J2
4	Siltajohde	P88,9x4	S 355 J2
25	Jatkoskappale	P76,1x5	S 355 J2
28	Lukkoruuvi	M16x110-8.8	SFS 2458
15	Kuusiomutteri	M16-8	SFS-ISO 4032
24	Aluslaatta	16-140 HV	SFS-ISO 7089
ALEMMAN TÖRMÄYSJOHTEEN JATKAMINEN			
31	Törmäysjohde	P76,1x5	S 355 J2
27	Jatkoskappale	P60,3x5	S 355 J2
29	Lukkoruuvi	M16x100-8.8	SFS 2458
15	Kuusiomutteri	M16-8	SFS-ISO 4032
24	Aluslaatta	16-140 HV	SFS-ISO 7089
VÄLIJOHTEEN JATKAMINEN			
30	Välijohde	P48,3x2,6	S 355 J2
26	Jatkoskappale	P40x3	Fe P01
39	Lukkoruuvi	M8x60-4.6	SFS 2458
36	Kuusiomutteri	M8-8	SFS-ISO 4032
35	Aluslaatta	8-140 HV	SFS-ISO 7089

Teräsosien kuumasinkitys:
osat 3, 4, 25, 27, 31 SYL 4.5.4
muut SFS-EN ISO 1461

Hitsiluokka: osat 3, 4, 31 B SFS-EN 25817
osa 30 C SFS-EN 25817

Liikevaran ollessa suurempi kuin ±50 mm annetaan sillan suunnitelmassa erikseen ohjeet liikuntajatkoksen tekemiseen.

OSAMITAT

SILTA- JA TÖRMÄYSJOHTEEN JATKAMINEN

△l	A	B	C	D	E	F	G	H	J	R
± 5	100	125	100	190	550	30	25	17	18	9
±10	97	125	95	184	554	30	30	17	18	9
±30	87	125	75	164	574	30	50	17	18	9
±50	77	125	55	144	594	30	70	17	18	9

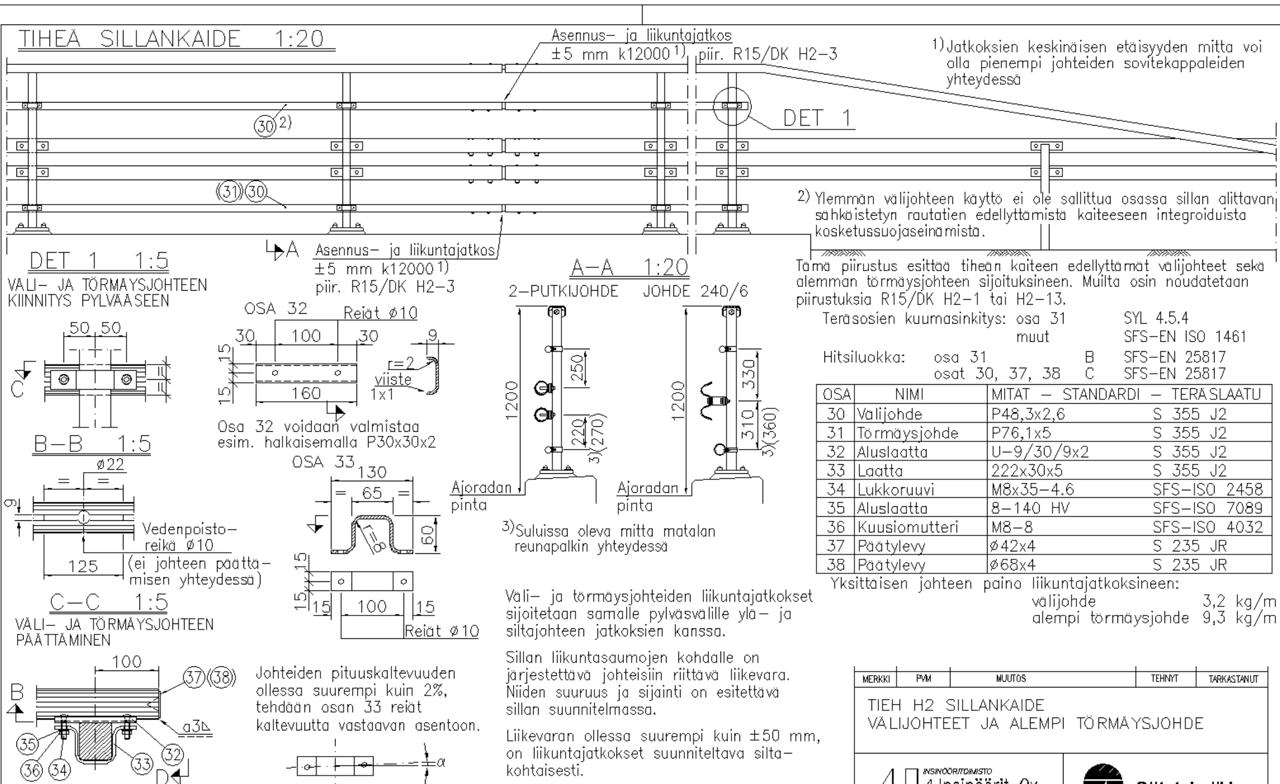
VÄLIJOHTEEN JATKAMINEN

△l	A	B	C	D	E	F	G	H	J	R
± 5	90	100	83	178	442	15	17	9	10	5
±10	87	100	78	172	446	15	22	9	10	5
±30	77	100	58	152	466	15	42	9	10	5
±50	67	100	38	132	486	15	62	9	10	5

TIEH H2 SILLANKAIDE
PUTKIJOHTEEN RUUVILIITOSJATKOS

Insinööritoimisto A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT. 25.11.02 Virpi Rainne
SUUNN. 25.11.02 Vesa Järvinen
TARK. 25.11.02 Leo Seppänen
MITTAK. 1:5 PIIR. NRO R15/DK H2-3
FILE: DK H2-3



1) Jatkoksien keskinäisen etäisyyden mitta voi olla pienempi johteiden sovitekappaleiden yhteydessä

2) Ylemmän välijohteen käyttö ei ole sallittua osassa sillan alittavan sähköistetyn rautatien edellyttämistä kaiteeseen integroiduista kosketussuojaseinämistä.

Osa 32 voidaan valmistaa esim. halkaisemalla P30x30x2

3) Suluissa oleva mitta matalan reunapalkin yhteydessä

Johteiden pituuskaltevuuden ollessa suurempi kuin 2%, tehdään osan 33 reiät kaltevuutta vastaavan asentoon.

Väli- ja törmäysjohteiden liikuntajatkokset sijoitetaan samalle pylväsvälille ylä- ja siltajohteen jatkoksien kanssa.

Sillan liikuntasaumojen kohdalle on järjestettävä johteisiin riittävä liikevara. Niiden suuruus ja sijainti on esitettävä sillan suunnitelmassa.

Liikevaran ollessa suurempi kuin ±50 mm, on liikuntajatkokset suunniteltava siltakohtaisesti.

Tämä piirustus esittää tiheän kaiteen edellyttämät välijohteet sekä alemman törmäysjohteen sijoituksineen. Muilta osin noudatetaan piirustuksia R15/DK H2-1 tai H2-13.

Teräsosien kuumasinkitys: osa 31 SYL 4.5.4
muut SFS-EN ISO 1461

Hitsiluokka: osa 31 B SFS-EN 25817
osat 30, 37, 38 C SFS-EN 25817

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
30	Välijohde	P48,3x2,6	S 355 J2
31	Törmäysjohde	P76,1x5	S 355 J2
32	Aluslaatta	U-9/30/9x2	S 355 J2
33	Laatta	222x30x5	S 355 J2
34	Lukkoruuvi	M8x35-4.6	SFS-ISO 2458
35	Aluslaatta	8-140 HV	SFS-ISO 7089
36	Kuusiomutteri	M8-8	SFS-ISO 4032
37	Päätylevy	ø42x4	S 235 JR
38	Päätylevy	ø68x4	S 235 JR

Yksittäisen johteen paino liikuntajatkoksineen:
välijohde 3,2 kg/m
alempi törmäysjohde 9,3 kg/m

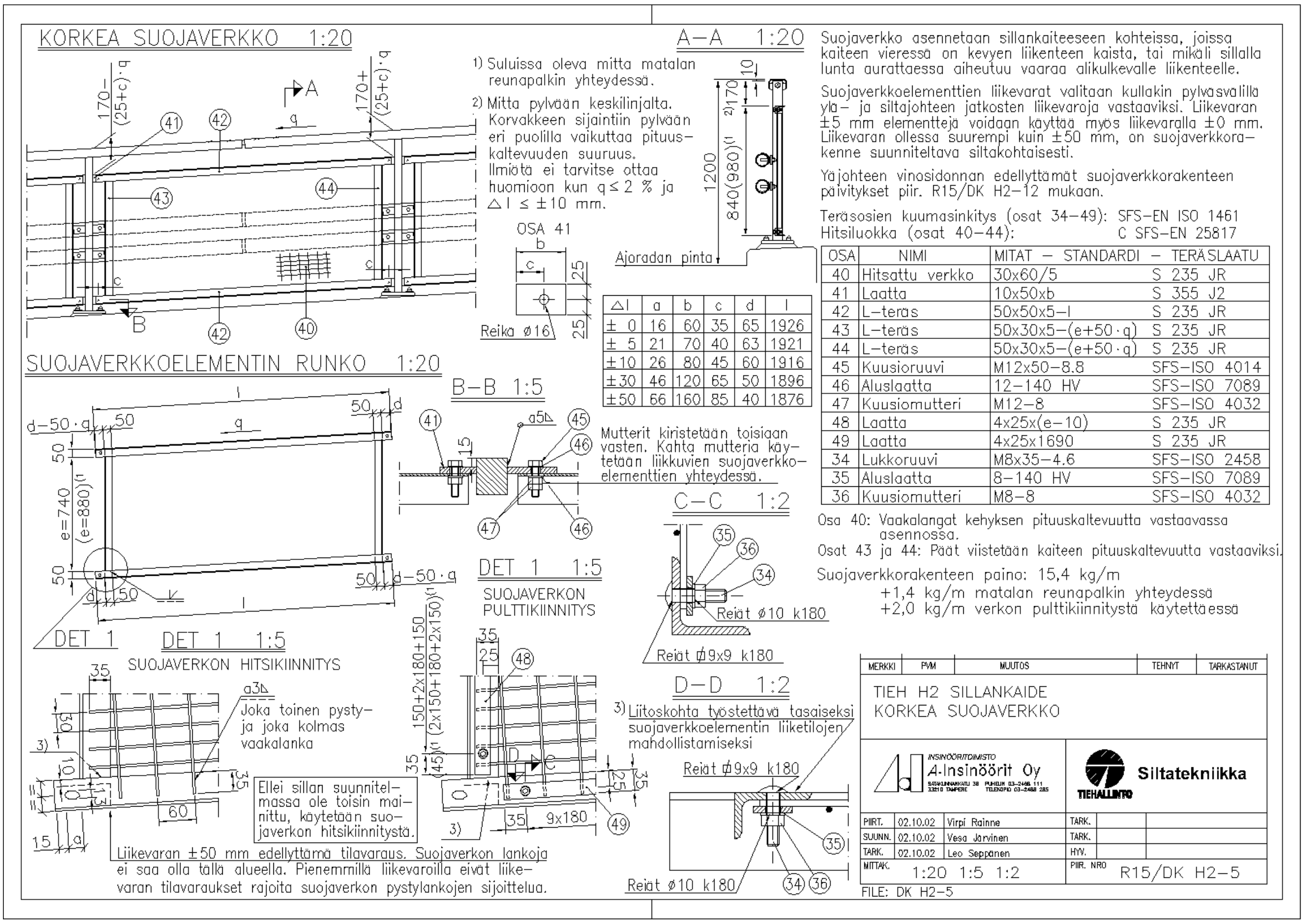
Osa 31: Osa harvan kaiteen runkoa kaikissa muissa tapauksissa, paitsi 2-putkijohteellisen kaiteen (piir. R15/DK H2-1) liittyessä korkeaan reunapalkkiin. Käyttöä edellytetään täten myös tämän piir. mukaisen tiheän kaiteen sekä verkkokaiteen (piir. R15/DK H2-5) yhteydessä em. tapauksissa. Korvaa tiheän kaiteen alemman välijohdeputken.

Osa 38: Käyttö osan 31 yhteydessä.

TIEH H2 SILLANKAIDE
VÄLIJOHTEET JA ALEMPI TÖRMÄYSJOHDE

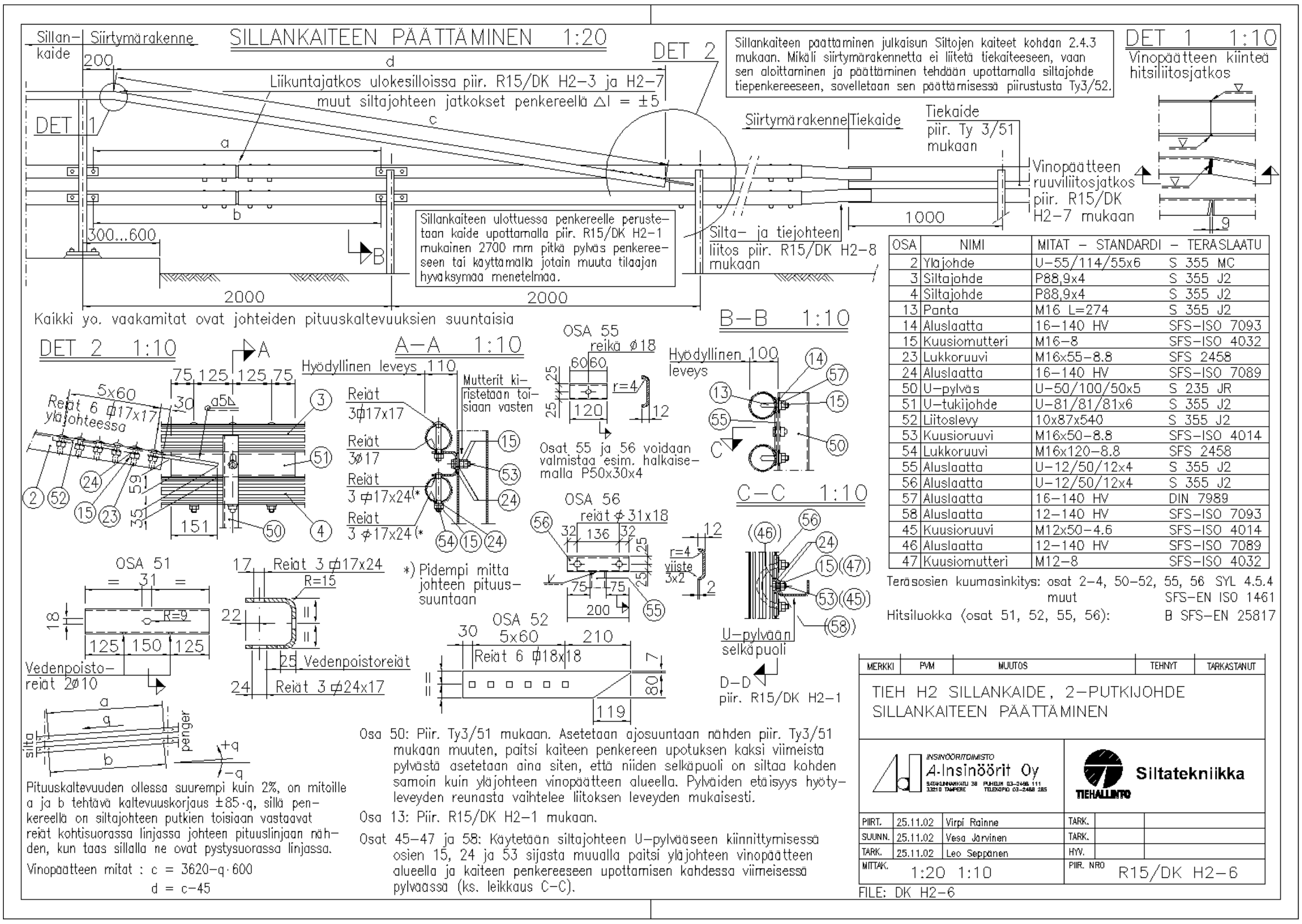
Insinööritoimisto A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT. 25.11.02 Virpi Rainne
SUUNN. 25.11.02 Vesa Järvinen
TARK. 25.11.02 Leo Seppänen
MITTAK. 1:20 1:5 PIIR. NRO R15/DK H2-4
FILE: DK H2-4

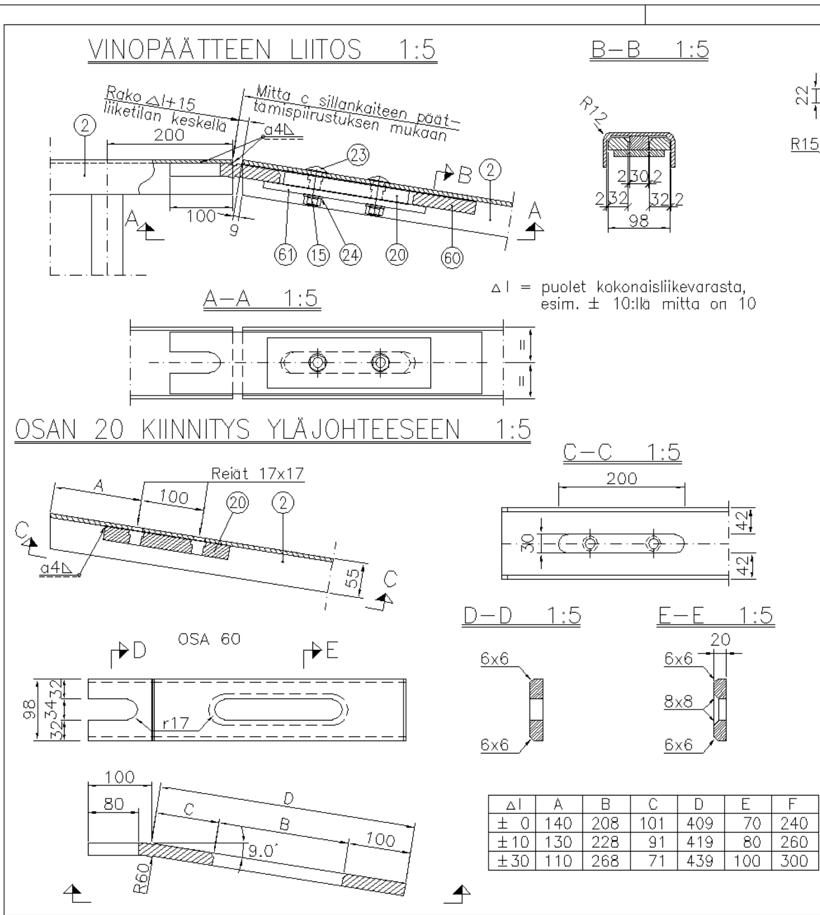


△l	a	b	c	d	l
± 0	16	60	35	65	1926
± 5	21	70	40	63	1921
±10	26	80	45	60	1916
±30	46	120	65	50	1896
±50	66	160	85	40	1876

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
40	Hitsattu verkko	30x60/5	S 235 JR
41	Laatta	10x50xb	S 355 J2
42	L-teräs	50x50x5–l	S 235 JR
43	L-teräs	50x30x5–(e+50·q)	S 235 JR
44	L-teräs	50x30x5–(e+50·q)	S 235 JR
45	Kuusioruuvi	M12x50–8.8	SFS-ISO 4014
46	Aluslaatta	12–140 HV	SFS-ISO 7089
47	Kuusiomutteri	M12–8	SFS-ISO 4032
48	Laatta	4x25x(e–10)	S 235 JR
49	Laatta	4x25x1690	S 235 JR
34	Lukkoruuvi	M8x35–4.6	SFS-ISO 2458
35	Aluslaatta	8–140 HV	SFS-ISO 7089
36	Kuusiomutteri	M8–8	SFS-ISO 4032



OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
2	Yläjohde	U-55/114/55x6	S 355 MC
3	Siltajohde	P88,9x4	S 355 J2
4	Siltajohde	P88,9x4	S 355 J2
13	Panta	M16 L=274	S 355 J2
14	Aluslaatta	16–140 HV	SFS-ISO 7093
15	Kuusiomutteri	M16–8	SFS-ISO 4032
23	Lukkoruuvi	M16x55–8.8	SFS 2458
24	Aluslaatta	16–140 HV	SFS-ISO 7089
50	U-pylväs	U-50/100/50x5	S 235 JR
51	U-tukijohde	U-81/81/81x6	S 355 J2
52	Liitoslevy	10x87x540	S 355 J2
53	Kuusioruuvi	M16x50–8.8	SFS-ISO 4014
54	Lukkoruuvi	M16x120–8.8	SFS 2458
55	Aluslaatta	U-12/50/12x4	S 355 J2
56	Aluslaatta	U-12/50/12x4	S 355 J2
57	Aluslaatta	16–140 HV	DIN 7989
58	Aluslaatta	12–140 HV	SFS-ISO 7093
45	Kuusioruuvi	M12x50–4.6	SFS-ISO 4014
46	Aluslaatta	12–140 HV	SFS-ISO 7089
47	Kuusiomutteri	M12–8	SFS-ISO 4032



△l	A	B	C	D	E	F
± 0	140	208	101	409	70	240
±10	130	228	91	419	80	260
±30	110	268	71	439	100	300

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
2	Ylajohde	U–55/114/55x6	S 355 MC
15	Kuusiomutteri	M16–8	SFS–ISO 4032
20	Vastakappale	30x22x200	S 355 J2
23	Lukkoruuvi	M16x55–8.8	SFS 2458
24	Aluslaatta	16–140 HV	SFS–ISO 7089
60	Jatkoskappale	20x98x507	S 355 J2
61	Tukikappale	10x80x240	S 355 J2

Teräsosien kuumasinkitys: osat 2, 20, 60, 61 SYL 4.5.4
muut SFS–EN ISO 1461

Hitsiluokka (osat 2, 20): B SFS–EN 25817

Liikevaran ollessa suurempi kuin ±30 mm annetaan sillan suunnitelmassa erikseen ohjeet liikuntajatkoksen tekemiseen.

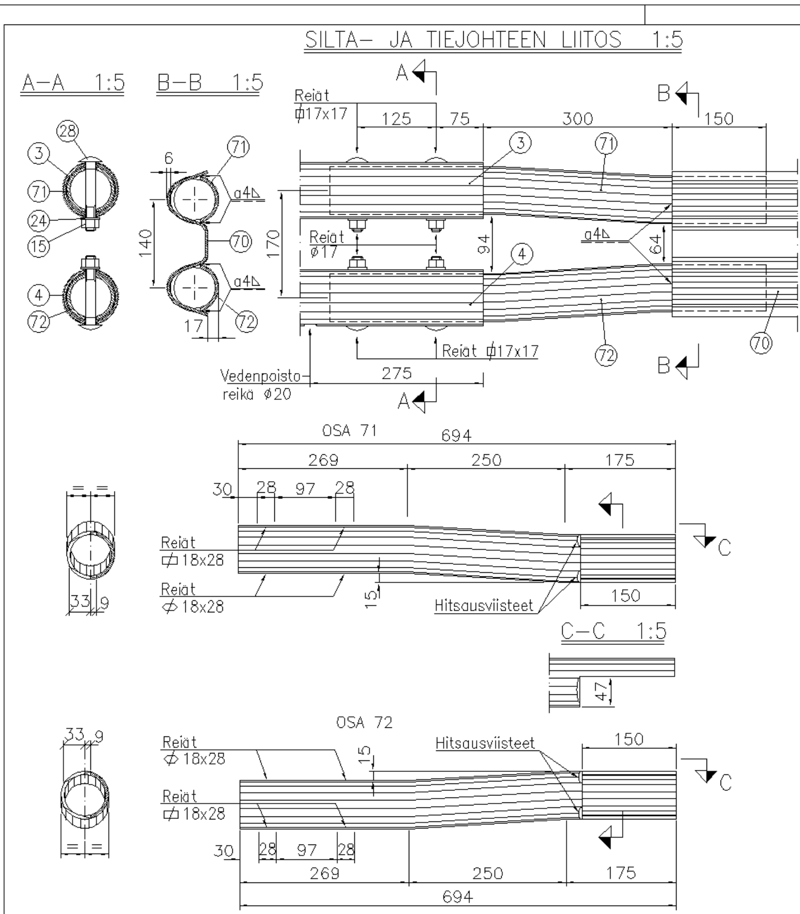
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

TIEH H2 SILLANKAIDE
VINOPÄÄTTEEN RUUVILIITOSJATKOS

INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:5		PIIR. NRO	R15/DK H2–7

FILE: DK H2–7



	NIMI	MITAT – STANDARDI – TERÄSLAATU	
3	Siltajohde	P88,9x4	S 355 J2
4	Siltajohde	P88,9x4 piir. Ko–1464	S 355 J2
70	Tiejohde	230/4	S 235 JR
71	Liitososa	P76,1x5	S 355 J2
72	Liitososa	P76,1x5	S 355 J2
15	Kuusiomutteri	M16–8	SFS–ISO 4032
24	Aluslaatta	16–140 HV	SFS–ISO 7089
28	Lukkoruuvi	M16x110–8.8	SFS 2458

Osa 70: Piir. Ko–1464 mukaan. Osien 71 ja 72 kiinnihitsaus ennen kuumasinkitystä.

Teräsosien kuumasinkitys: osat 3, 4, 70–72 SYL 4.5.4
muut SFS–EN ISO 1461

Hitsiluokka (osat 70–72): B SFS–EN 25817

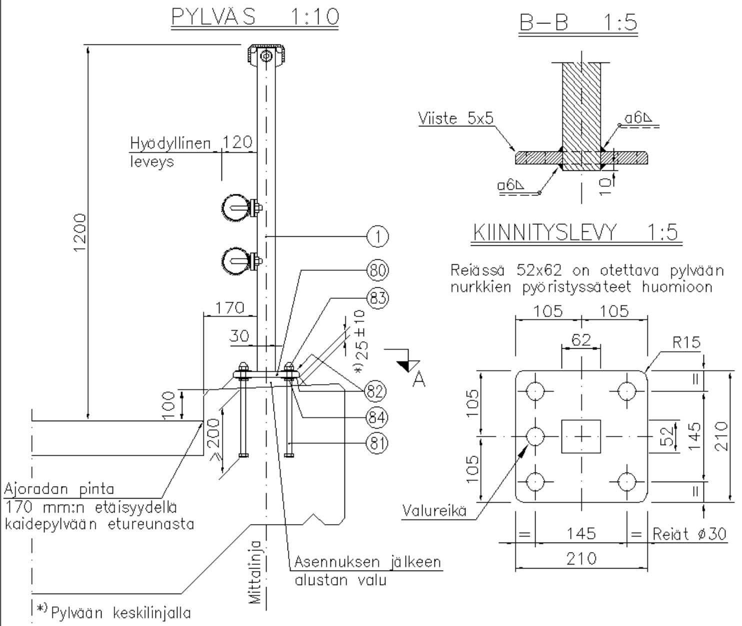
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

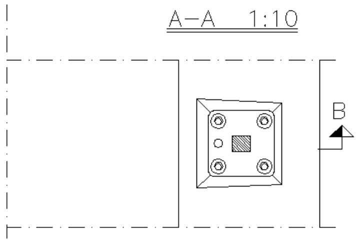
TIEH H2 SILLANKAIDE, 2–PUTKIJOHDE
SILTA– JA TIEJOHTEEN LIITOS

INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:5		PIIR. NRO	R15/DK H2–8

FILE: DK H2–8





Kaiteen asentamisessa noudatetaan Sillanrakentamisen yleisissä laatuvaatimuksissa (SYL 7) annettua ohjetta.

Kiinnityspultit asennetaan reunapalkin valuun ryhmänä. Pulttien kuumasinkityksen on oltava riittävän passivoitunut. Pulttiryhmä kootaan vaneriseen kaaviolevyyn, levyn ylä- ja alapuolelle tulevien pulttien kiristysmuttereiden avulla. Pultin on pysyttävä pystysuorassa valun aikana. Kaaviolevy naulataan reunapalkin muottiin.

Kaidepylväitä asennettaessa säädetään kiinnityslevyn alapuolelle tulevilla muttereilla pylväälle oikea korkeusasema.

Asennuksen jälkeen suoritetaan alustan valu kutistumattomalla juotoslaastilla, jonka puristuslujuus ≥35 N/mm² ja P-luku ≥P50. Valu ei saa nousta reunoiltaan kiinnistyslevyn alapinnan tasoa ylemmäksi.

Kiinnityspultteihin jätetään kiinnityslevyn yläpuolista kierrettä jäljelle 20 ±3 mm. Muttereita ei saa kiertää liian lyhyisiin pultteihin. Mikäli pultit joudutaan asennuksen jälkeen katkaisemaan oikeaan pituuteensa, on muu kaiderakenne suojattava katkaisutyön aikaiselta kipinäsuihkulta. Katkaistujen pulttien päät käsitellään sinkkipölymaalilla.

OSA	NIMI	MITAT – STANDARDI	– TERÄSLAATU
1	Kaidepylväs	50x60x1060	S 235 J2
80	Kiinnityslevy	210x210x20	S 355 J2
81	Kuusioruuvi	M16x300–8.8	SFS–ISO 4014
82	Aluslaatta	16–140 HV	SFS–ISO 7093
83	Hattumutteri	M16–8	DIN 1587
84	Matala mutteri	M16–8	SFS–ISO 4035

Harvan kaiteen paino liikuntajatkoksineen 46,6 kg/m

Osa 81: Kierreosan pituus 100 mm

Osa 83: Saatavuussyistä voidaan tilaajan hankekohtaisella erillishyväksynnällä käyttää kuumasinkityn teräksen sijasta A4–teräslaatua.

Teräsosien kuumasinkitys: osat 1, 80 SYL 4.5.4
muut SFS–EN ISO 1461

Hitsiluokka (osat 1, 80): B SFS–EN 25817

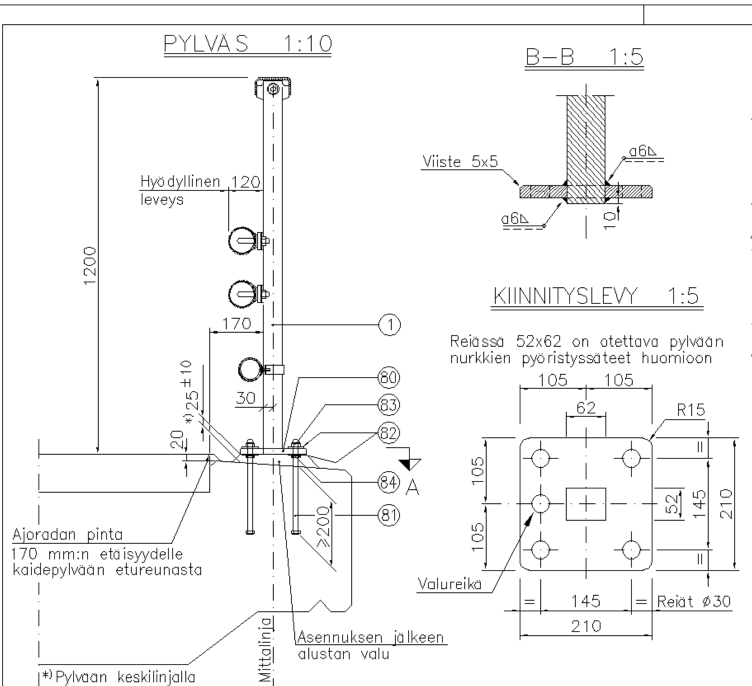
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

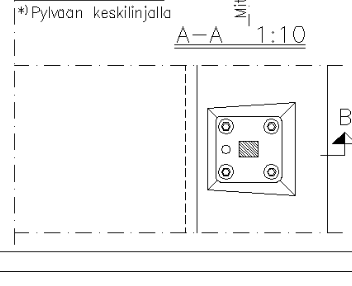
TIEH H2 SILLANKAIDE , 2–PUTKIJOHDE
PULTTIKIINNITYS KORKEAAN REUNAPALKKIIN

INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:10 1:5		PIIR. NRO	R15/DK H2–9

FILE: DK H2–9





Kaiteen asentamisessa noudatetaan Sillanrakentamisen yleisissä laatuvaatimuksissa (SYL 7) annettua ohjetta.

Kiinnityspultit asennetaan reunapalkin valuun ryhmänä. Pulttien kuumasinkityksen on oltava riittävan passivoitunut. Pulttiryhma kootaan vaneriseen kaaviolevyyn, levyn ylä- ja alapuolelle tulevien pulttien kiristysmuttereiden avulla. Pultin on pysyttävä pystysuorassa valun aikana. Kaaviolevy naulataan reunapalkin muottiin.

Kaidepylväitä asennettaessa säädetään kiinnityslevyn alapuolelle tulevilla muttereilla pylväälle oikea korkeusasema.

Asennuksen jälkeen suoritetaan alustan valu kutistumattomalla juotoslaastilla, jonka puristuslujuus ≥ 35 N/mm² ja P-luku ≥ P50. Valu ei saa nousta reunoiltaan kiinnistyslevyn alapinnan tasoa ylemmäksi.

Kiinnityspultteihin jätetään kiinnityslevyn yläpuolista kierrettä jäljelle 20 ±3 mm. Muttereita ei saa kiertää liian lyhyisiin pultteihin. Mikäli pultit joudutaan asennuksen jälkeen katkaisemaan oikeaan pituuteensa, on muu kaiderakenne suojattava katkaisutyön aikaiselta kipinäsuihkulta. Katkaistujen pulttien päät käsitellään sinkkipöymaalilla.

OSA	NIMI	MITAT – STANDARDI	– TERÄSLAATU
1	Kaidepylväs	50x60x1203	S 235 J2
80	Kiinnityslevy	210x210x20	S 355 J2
81	Kuusioruuvi	M16x300–8.8	SFS–ISO 4014
82	Aluslaatta	16–140 HV	SFS–ISO 7093
83	Hattumutteri	M16–8	DIN 1587
84	Matala mutteri	M16–8	SFS–ISO 4035

Harvan kaiteen paino liikuntajatkoksineen 57,5 kg/m
(sis. alemman törmäysjohteen)

Osa 81: Kierreosan pituus 100 mm

Osa 83: Saatavuussyistä voidaan tilaajan hankekohtaisella erillishyväksynnällä käyttää kuumasinkityn teräksen sijasta A4–teräslaatua.

Teräsosien kuumasinkitys: osat 1, 80 SYL 4.5.4
muut SFS–EN ISO 1461

Hitsiluokka (osat 1, 80): B SFS–EN 25817

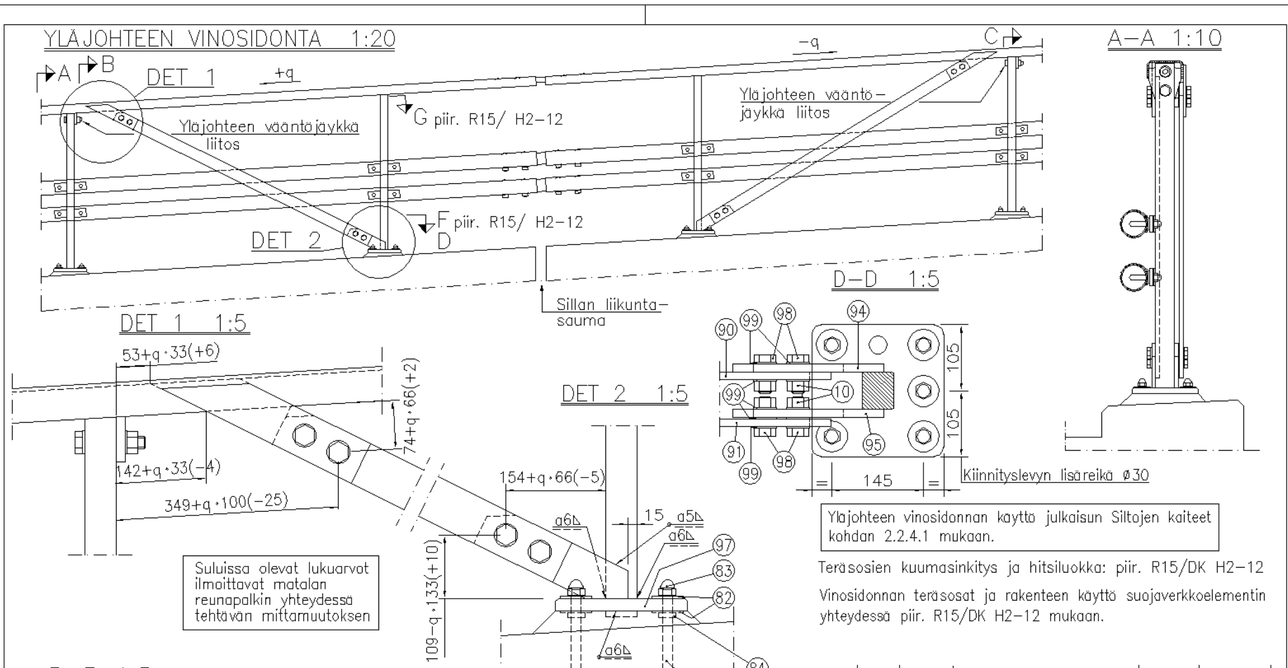
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

TIEH H2 SILLANKAIDE , 2–PUTKIJOHDE
PULTTIKIINNITYS MATALAAN REUNAPALKKIIN

INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:10 1:5		PIIR. NRO	R15/DK H2–10

FILE: DK H2–10



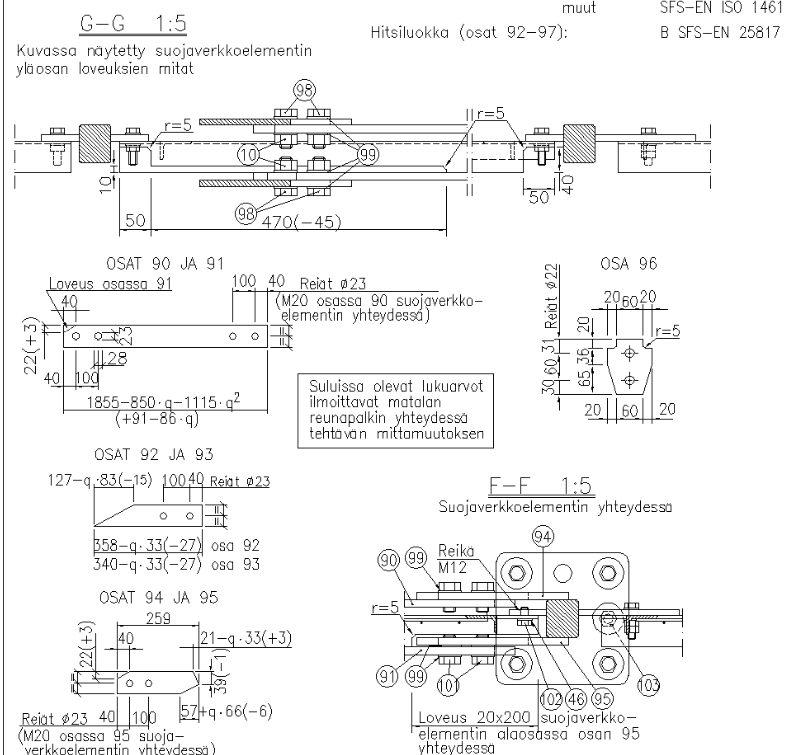
MERKKI | PVM | MUUTOS | TEHNYT | TARKASTANUT

TIEH H2 SILLANKAIDE
YLÄJOHTEEN VINOSIDONTA, RAKENNE

INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:20 1:10 1:5		PIIR. NRO	R15/DK H2-11

FILE: DK H2-11



Teräsosien kuumasinkitys: osat 90–97 SYL 4.5.4
muut SFS-EN ISO 1461
Hitsiluokka (osat 92–97): B SFS-EN 25817

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
81	Kuusioruuvi	M16x300–8.8	SFS-ISO 4014
82	Aluslaatta	16–200 HV	SFS-ISO 7093
83	Hattumutteri	M16–8	DIN 1587
84	Matala mutteri	M16–8	SFS-ISO 4035
90	Vinosidontalaatta	70x12	S 355 J2
91	Vinosidontalaatta	70x12	S 355 J2
92	Laatta	70x10	S 355 J2
93	Laatta	70x10	S 355 J2
94	Laatta	70x12	S 355 J2
95	Laatta	70x12	S 355 J2
96	Laatta	100x121x15	S 355 J2
97	Kiinnityslevy	210x210x20	S 355 J2
98	Kuusioruuvi	M20x50–8.8	SFS-ISO 4017
99	Aluslaatta	20–140 HV	SFS-ISO 7089
10	Kuusiomutteri	M20–8	SFS-ISO 4032
100	Kuusioruuvi	M20x100–8.8	SFS-ISO 4014
8	Kuusioruuvi	M20x110–8.8	SFS-ISO 4014
9	Aluslaatta	20–140 HV	SFS-ISO 7089
101	Kuusioruuvi	M20x35	SFS-ISO 4017
102	Kuusioruuvi	M12x20	SFS-ISO 4017
46	Aluslaatta	12–140 HV	SFS-ISO 7089
103	Kuusiomutteri	M16–8	SFS-ISO 4032

Osa 81: kierreosan pituus 100 mm
Osa 97: osa 80 (piir. R15/DK H2-9) varustettuna lisäkiinnitysreiällä leikkauksen D-D (piir. R15/DK H2-11) mukaan
Osa 103: käytetään osan 83 sijasta suojaverkkoelementin alle jäävän kiinnityspultin yhteydessä

Vinosidonnan lisäpaino per kaidelinja: 63,4 kg + 1,8 kg matalan reunapalkin yhteydessä

ks. piir. R15/DK H2-11

Mikäli yläjohteen vinosidonnan yhteydessä käytetään suojaverkkoa (piir. R15/DK H2-5), asennetaan se paikoilleen ennen osia 90, 91 ja 99. Suojaverkkoelementtiin tehdään leikkauksien F ja G mukaiset loveukset ja vinosidonnan pylvään pohjalevyyn kiinnittymisen yhteydessä käytetään osien 90 ja 95 lisäksi suojaverkon pylvään kiinnityslaatassa kierteistettyä reikää.

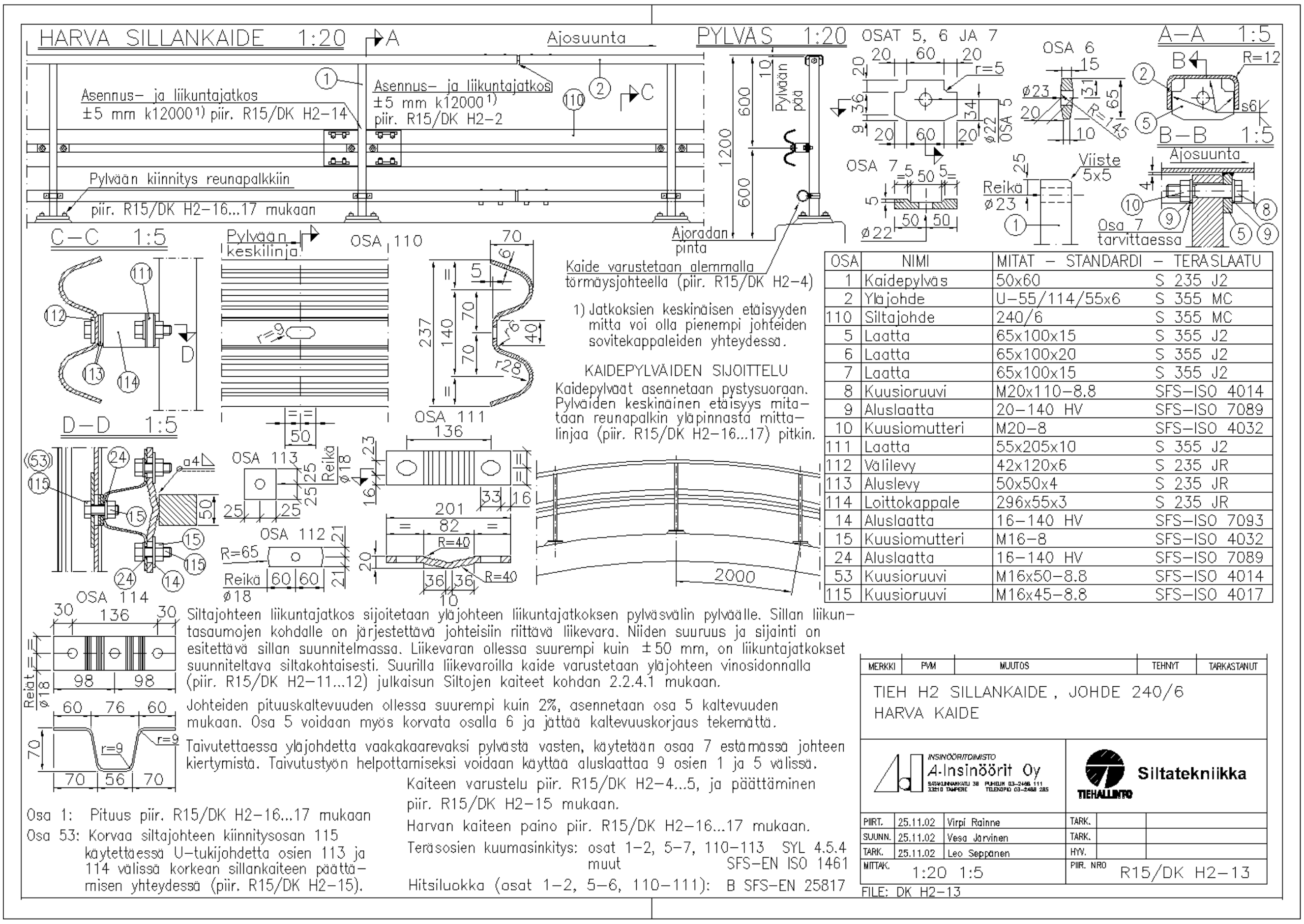
MERKKI | PVM | MUUTOS | TEHNYT | TARKASTANUT

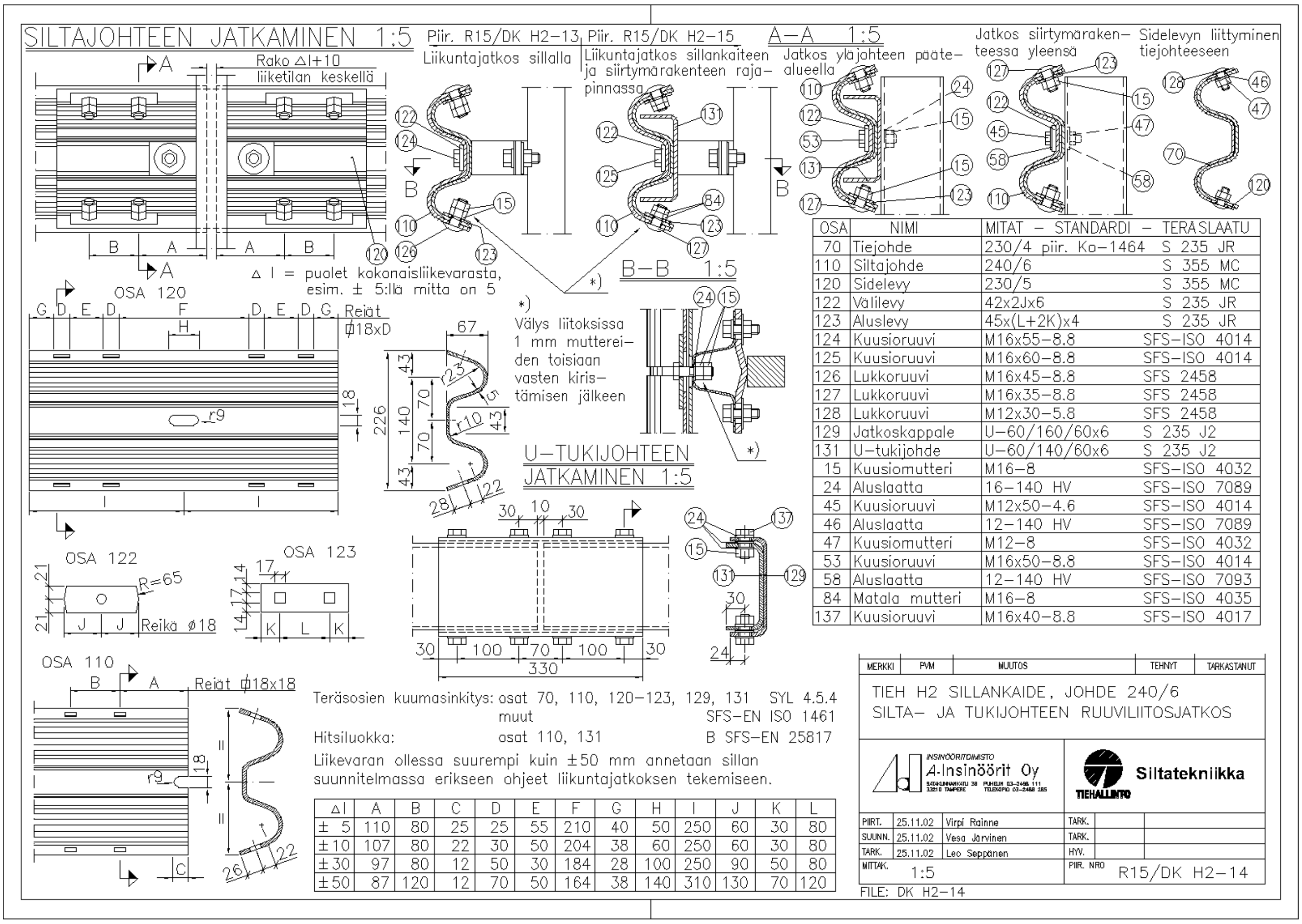
TIEH H2 SILLANKAIDE
YLÄJOHTEEN VINOSIDONTA, OSAT JA SUOJAVERKKOELEMENTTI

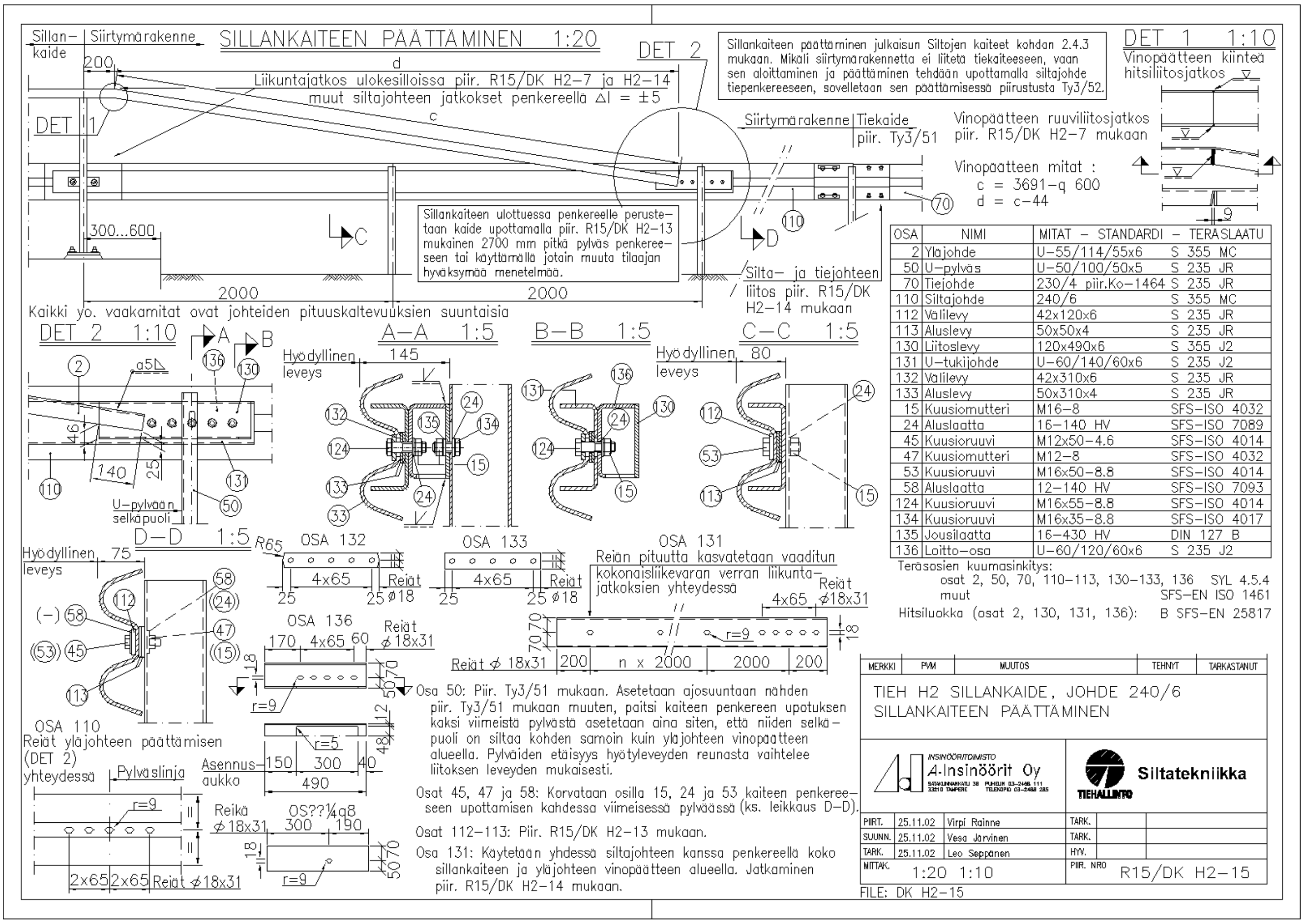
INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:5		PIIR. NRO	R15/DK H2-12

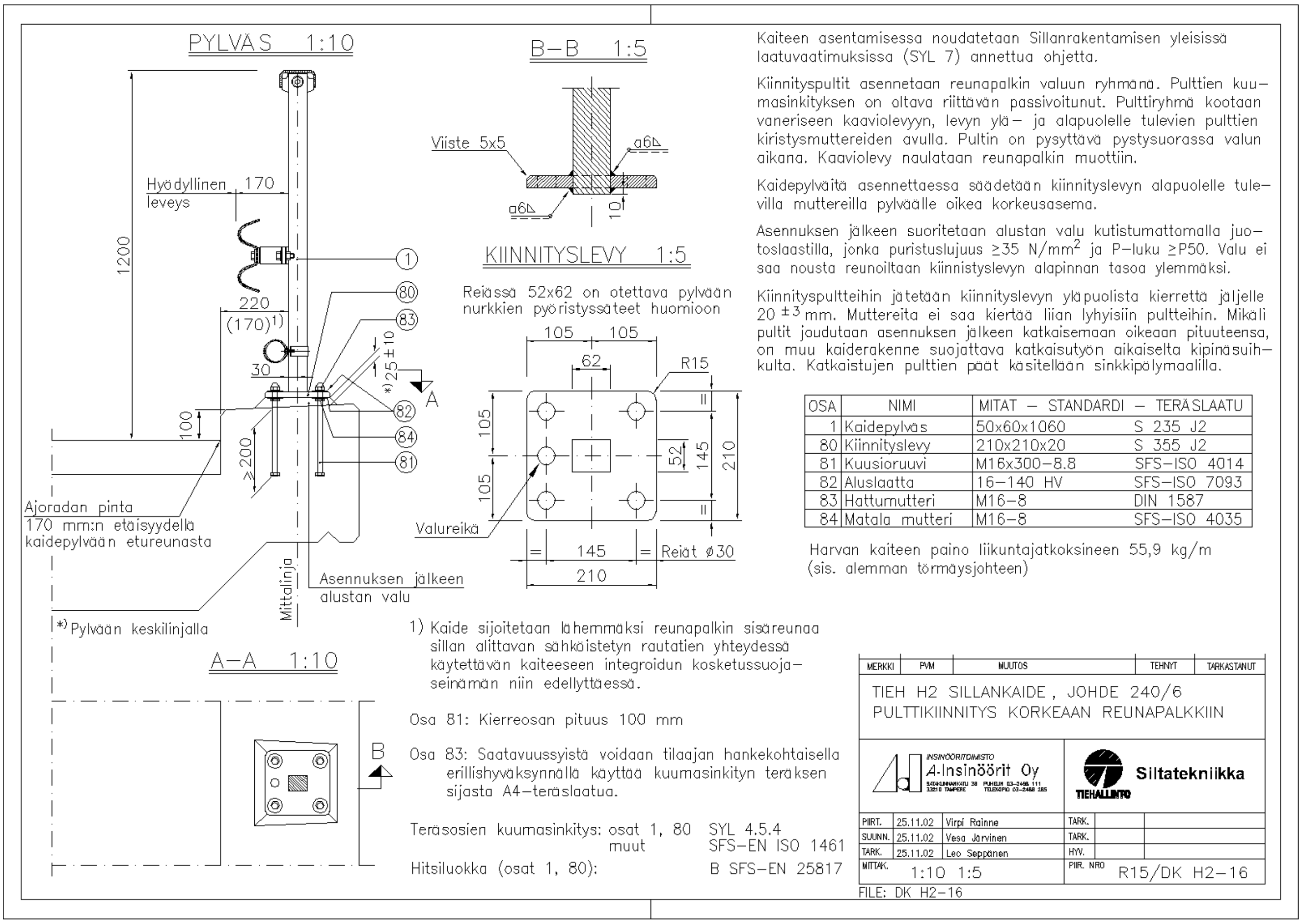
FILE: DK H2-12


HARVA SILLANKAIDE 1:20
Ajosuunta
Asennus- ja liikuntajatkos ±5 mm k12000 1) piir. R15/DK H2-14
Asennus- ja liikuntajatkos ±5 mm k12000 1) piir. R15/DK H2-2
Pylvään kiinnitys reunapalkkiin piir. R15/DK H2-16...17 mukaan
PYLVÄS 1:20
Pylvään pää
Ajoradan pinta
Kaide varustetaan alemmalla törmäysjohteella (piir. R15/DK H2-4)
1) Jatkoksien keskinäisen etäisyyden mitta voi olla pienempi johteiden sovitekappaleiden yhteydessä.
KAIDEPYLVÄIDEN SIJOITTELU
Kaidepylvaat asennetaan pystysuoraan. Pylväiden keskinäinen etäisyys mitataan reunapalkin yläpinnassa mittalinjaa (piir. R15/DK H2-16...17) pitkin.
OSAT 5, 6 JA 7
OSA 6
OSA 7
A-A 1:5
B-B 1:5
Viiste 5x5
Reikä ø23
Osa 7 tarvittaessa
C-C 1:5
D-D 1:5
Pylvään keskilinja
OSA 110
OSA 111
OSA 112
OSA 113
OSA 114
Reikä ø18
Reiät ø18
Siltajohteen liikuntajatkos sijoitetaan yläjohteen liikuntajatkoksen pylväsvälin pylväälle. Sillan liikuntasaumojen kohdalle on järjestettävä johteisiin riittävä liikevara. Niiden suuruus ja sijainti on esitettävä sillan suunnitelmassa. Liikevaran ollessa suurempi kuin ±50 mm, on liikuntajatkokset suunniteltava siltakohtaisesti. Suurilla liikevaroilla kaide varustetaan yläjohteen vinosidonnalla (piir. R15/DK H2-11...12) julkaisun Siltojen kaiteet kohdan 2.2.4.1 mukaan.
Johteiden pituuskaltevuuden ollessa suurempi kuin 2%, asennetaan osa 5 kaltevuuden mukaan. Osa 5 voidaan myös korvata osalla 6 ja jättää kaltevuuskorjaus tekemättä.
Taivutettaessa yläjohdetta vaakakaarevaksi pylvästä vasten, käytetään osaa 7 estämässä johteen kiertymistä. Taivutustyön helpottamiseksi voidaan käyttää aluslaattaa 9 osien 1 ja 5 välissä.
Kaiteen varustelu piir. R15/DK H2-4...5, ja päättäminen piir. R15/DK H2-15 mukaan.
Harvan kaiteen paino piir. R15/DK H2-16...17 mukaan.
Teräsosien kuumasinkitys: osat 1-2, 5-7, 110-113 SYL 4.5.4
muut SFS-EN ISO 1461
Hitsiluokka (osat 1-2, 5-6, 110-111): B SFS-EN 25817
Osa 1: Pituus piir. R15/DK H2-16...17 mukaan
Osa 53: Korvaa siltajohteen kiinnitysosan 115 käytettäessä U-tukijohdetta osien 113 ja 114 välissä korkean sillankaiteen päättämisen yhteydessä (piir. R15/DK H2-15).
OSA | NIMI | MITAT - STANDARDI - TERÄSLAATU
1 | Kaidepylväs | 50x60 | S 235 J2
2 | Yläjohde | U-55/114/55x6 | S 355 MC
110 | Siltajohde | 240/6 | S 355 MC
5 | Laatta | 65x100x15 | S 355 J2
6 | Laatta | 65x100x20 | S 355 J2
7 | Laatta | 65x100x15 | S 355 J2
8 | Kuusioruuvi | M20x110-8.8 | SFS-ISO 4014
9 | Aluslaatta | 20-140 HV | SFS-ISO 7089
10 | Kuusiomutteri | M20-8 | SFS-ISO 4032
111 | Laatta | 55x205x10 | S 355 J2
112 | Välilevy | 42x120x6 | S 235 JR
113 | Aluslevy | 50x50x4 | S 235 JR
114 | Loittokappale | 296x55x3 | S 235 JR
14 | Aluslaatta | 16-140 HV | SFS-ISO 7093
15 | Kuusiomutteri | M16-8 | SFS-ISO 4032
24 | Aluslaatta | 16-140 HV | SFS-ISO 7089
53 | Kuusioruuvi | M16x50-8.8 | SFS-ISO 4014
115 | Kuusioruuvi | M16x45-8.8 | SFS-ISO 4017
MERKKI | PVM | MUUTOS | TEHNYT | TARKASTANUT
TIEH H2 SILLANKAIDE, JOHDE 240/6
HARVA KAIDE
A-Insinöörit Oy
Siltatekniikka
TIEHALLINTO
PIIRT. 25.11.02 Virpi Rainne
SUUNN. 25.11.02 Vesa Järvinen
TARK. 25.11.02 Leo Seppänen
MITTAK. 1:20 1:5
PIIR. NRO R15/DK H2-13
FILE: DK H2-13

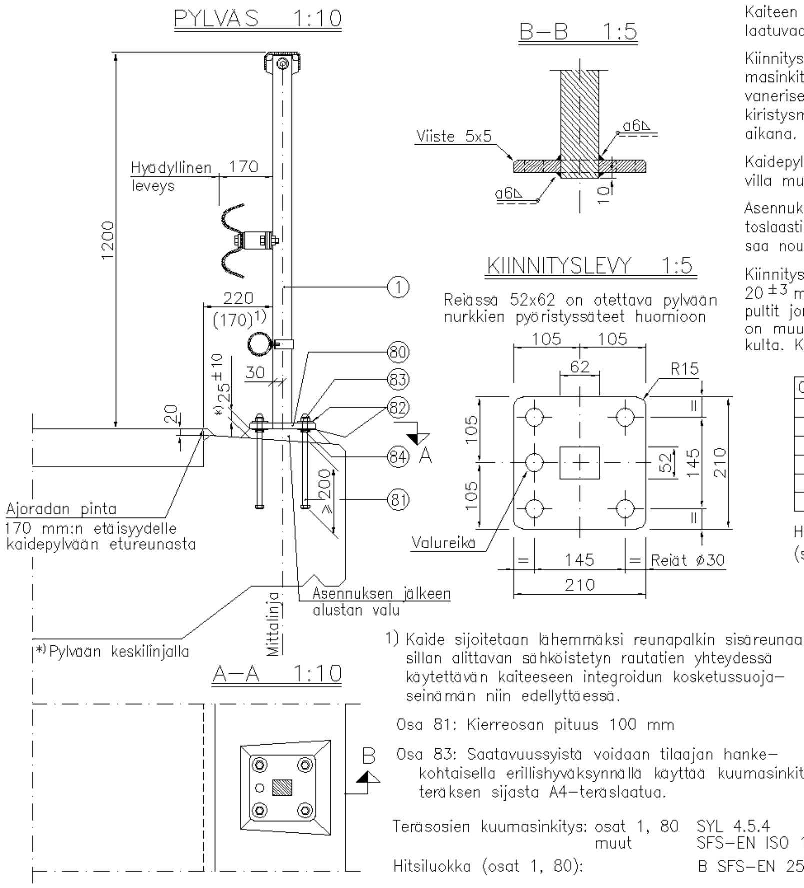

SILTAJOHTEEN JATKAMINEN 1:5
Rako Δl+10 liiketilan keskellä
Δ l = puolet kokonaisliikevarasta, esim. ± 5:llä mitta on 5
Piir. R15/DK H2-13 Liikuntajatkos sillalla
Piir. R15/DK H2-15 Liikuntajatkos sillankaiteen ja siirtymärakenteen rajapinnassa
A-A 1:5
Jatkos yläjohteen pääte-alueella
Jatkos siirtymärakenteessa yleensä
Sidelevyn liittyminen tiejohteeseen
B-B 1:5
OSA 120
Reiät ø18xD
*) Välys liitoksissa 1 mm muttereiden toisiaan vasten kiristämisen jälkeen
U-TUKIJOHTEEN JATKAMINEN 1:5
OSA 122
Reikä ø18
OSA 123
OSA 110
Reiät ø18x18
Teräsosien kuumasinkitys: osat 70, 110, 120-123, 129, 131 SYL 4.5.4
muut SFS-EN ISO 1461
Hitsiluokka: osat 110, 131 B SFS-EN 25817
Liikevaran ollessa suurempi kuin ±50 mm annetaan sillan suunnitelmassa erikseen ohjeet liikuntajatkoksen tekemiseen.
Δl | A | B | C | D | E | F | G | H | I | J | K | L
± 5 | 110 | 80 | 25 | 25 | 55 | 210 | 40 | 50 | 250 | 60 | 30 | 80
± 10 | 107 | 80 | 22 | 30 | 50 | 204 | 38 | 60 | 250 | 60 | 30 | 80
± 30 | 97 | 80 | 12 | 50 | 30 | 184 | 28 | 100 | 250 | 90 | 50 | 80
± 50 | 87 | 120 | 12 | 70 | 50 | 164 | 38 | 140 | 310 | 130 | 70 | 120
OSA | NIMI | MITAT - STANDARDI - TERÄSLAATU
70 | Tiejohde | 230/4 piir. Ka-1464 | S 235 JR
110 | Siltajohde | 240/6 | S 355 MC
120 | Sidelevy | 230/5 | S 355 MC
122 | Välilevy | 42x2Jx6 | S 235 JR
123 | Aluslevy | 45x(L+2K)x4 | S 235 JR
124 | Kuusioruuvi | M16x55-8.8 | SFS-ISO 4014
125 | Kuusioruuvi | M16x60-8.8 | SFS-ISO 4014
126 | Lukkoruuvi | M16x45-8.8 | SFS 2458
127 | Lukkoruuvi | M16x35-8.8 | SFS 2458
128 | Lukkoruuvi | M12x30-5.8 | SFS 2458
129 | Jatkoskappale | U-60/160/60x6 | S 235 J2
131 | U-tukijohde | U-60/140/60x6 | S 235 J2
15 | Kuusiomutteri | M16-8 | SFS-ISO 4032
24 | Aluslaatta | 16-140 HV | SFS-ISO 7089
45 | Kuusioruuvi | M12x50-4.6 | SFS-ISO 4014
46 | Aluslaatta | 12-140 HV | SFS-ISO 7089
47 | Kuusiomutteri | M12-8 | SFS-ISO 4032
53 | Kuusioruuvi | M16x50-8.8 | SFS-ISO 4014
58 | Aluslaatta | 12-140 HV | SFS-ISO 7093
84 | Matala mutteri | M16-8 | SFS-ISO 4035
137 | Kuusioruuvi | M16x40-8.8 | SFS-ISO 4017
MERKKI | PVM | MUUTOS | TEHNYT | TARKASTANUT
TIEH H2 SILLANKAIDE, JOHDE 240/6
SILTA- JA TUKIJOHTEEN RUUVILIITOSJATKOS
A-Insinöörit Oy
Siltatekniikka
TIEHALLINTO
PIIRT. 25.11.02 Virpi Rainne
SUUNN. 25.11.02 Vesa Järvinen
TARK. 25.11.02 Leo Seppänen
MITTAK. 1:5
PIIR. NRO R15/DK H2-14
FILE: DK H2-14



OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
2	Yläjohde	U–55/114/55x6	S 355 MC
50	U–pylväs	U–50/100/50x5	S 235 JR
70	Tiejohde	230/4 piir.Ko–1464	S 235 JR
110	Siltajohde	240/6	S 355 MC
112	Välilevy	42x120x6	S 235 JR
113	Aluslevy	50x50x4	S 235 JR
130	Liitoslevy	120x490x6	S 235 J2
131	U–tukijohde	U–60/140/60x6	S 235 J2
132	Välilevy	42x310x6	S 235 JR
133	Aluslevy	50x310x4	S 235 JR
15	Kuusiomutteri	M16–8	SFS–ISO 4032
24	Aluslaatta	16–140 HV	SFS–ISO 7089
45	Kuusioruuvi	M12x50–4.6	SFS–ISO 4014
47	Kuusiomutteri	M12–8	SFS–ISO 4032
53	Kuusioruuvi	M16x50–8.8	SFS–ISO 4014
58	Aluslaatta	12–140 HV	SFS–ISO 7093
124	Kuusioruuvi	M16x55–8.8	SFS–ISO 4014
134	Kuusioruuvi	M16x35–8.8	SFS–ISO 4017
135	Jousilaatta	16–430 HV	DIN 127 B
136	Loitto–osa	U–60/120/60x6	S 235 J2



OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
1	Kaidepylväs	50x60x1060	S 235 J2
80	Kiinnityslevy	210x210x20	S 355 J2
81	Kuusioruuvi	M16x300–8.8	SFS–ISO 4014
82	Aluslaatta	16–140 HV	SFS–ISO 7093
83	Hattumutteri	M16–8	DIN 1587
84	Matala mutteri	M16–8	SFS–ISO 4035



1) Kaide sijoitetaan lähemmäksi reunapalkin sisäreunaa sillan alittavan sähköistetyn rautatien yhteydessä käytettävän kaiteeseen integroidun kosketussuojaseinämän niin edellyttäessä.

Osa 81: Kierreosan pituus 100 mm

Osa 83: Saatavuussyistä voidaan tilaajan hankekohtaisella erillishyväksynnällä käyttää kuumasinkityn teräksen sijasta A4–teräslaatua.

Teräsosien kuumasinkitys: osat 1, 80 SYL 4.5.4
muut SFS–EN ISO 1461

Hitsiluokka (osat 1, 80): B SFS–EN 25817

Kaiteen asentamisessa noudatetaan Sillanrakentamisen yleisissä laatuvaatimuksissa (SYL 7) annettua ohjetta.

Kiinnityspultit asennetaan reunapalkin valuun ryhmänä. Pulttien kuumasinkityksen on oltava riittävän passivoitunut. Pulttiryhmä kootaan vaneriseen kaaviolevyyn, levyn ylä- ja alapuolelle tulevien pulttien kiristysmuttereiden avulla. Pultin on pysyttävä pystysuorassa valun aikana. Kaaviolevy naulataan reunapalkin muottiin.

Kaidepylväitä asennettaessa säädetään kiinnityslevyn alapuolelle tulevilla muttereilla pylväälle oikea korkeusasema.

Asennuksen jälkeen suoritetaan alustan valu kutistumattomalla juotoslaastilla, jonka puristuslujuus ≥ 35 N/mm² ja P–luku ≥ P50. Valu ei saa nousta reunoiltaan kiinnityslevyn alapinnan tasoa ylemmäksi.

Kiinnityspultteihin jätetään kiinnityslevyn yläpuolista kierrettä jäljelle 20 ±3 mm. Muttereita ei saa kiertää liian lyhyisiin pultteihin. Mikäli pultit joudutaan asennuksen jälkeen katkaisemaan oikeaan pituuteensa, on muu kaiderakenne suojattava katkaisutyön aikaiselta kipinäsuihkulta. Katkaistujen pulttien päät käsitellään sinkkipölymaalilla.

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
1	Kaidepylväs	50x60x1203	S 235 J2
80	Kiinnityslevy	210x210x20	S 355 J2
81	Kuusioruuvi	M16x300–8.8	SFS–ISO 4014
82	Aluslaatta	16–140 HV	SFS–ISO 7093
83	Hattumutteri	M16–8	DIN 1587
84	Matala mutteri	M16–8	SFS–ISO 4035

Harvan kaiteen paino liikuntajatkoksineen 57,6 kg/m (sis. alemman törmäysjohteen)

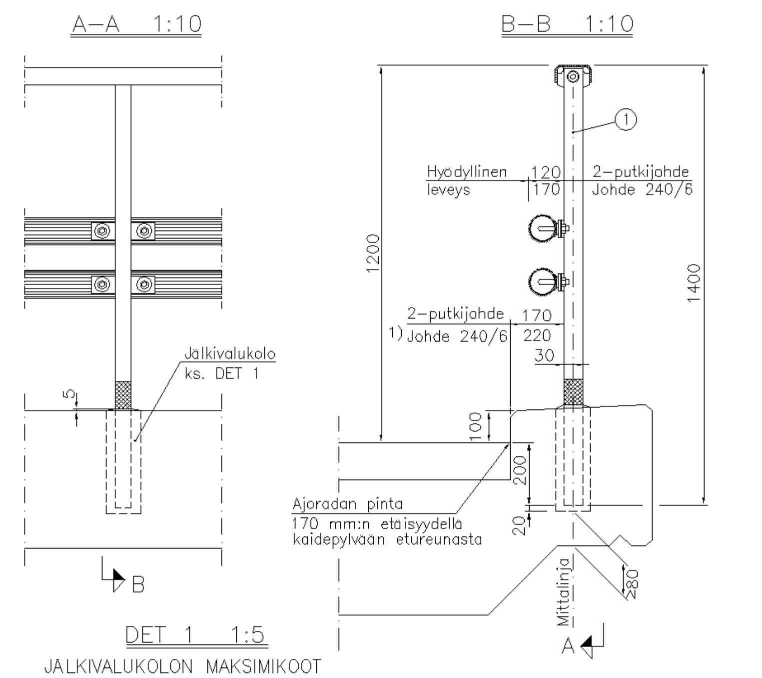
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

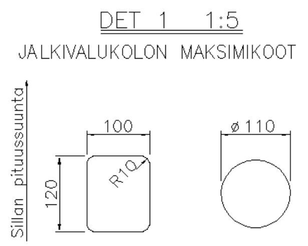
TIEH H2 SILLANKAIDE, JOHDE 240/6
PULTTIKIINNITYS MATALAAN REUNAPALKKIIN

A-Insinöörit Oy — Siltatekniikka, TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:10 1:5		PIIR. NRO	R15/DK H2–17

FILE: DK H2–17





1) Mitta 170 myös siltajohteella 240/6 varustetulla kaiteella sillan alittavan sähköistetyn rautatien yhteydessä käytettävän kaiteeseen integroidun kosketussuojaseinämän niin edellyttäessä.

Kaiteen asentamisessa noudatetaan Sillanrakentamisen yleisissä laatuvaatimuksissa (SYL 7) annettua ohjetta.

Kaidepylvään alapää pinnoitetaan kuumasinkityksen päälle tulevalla epoksimaalilla (80 μm) 400 mm:n matkalta.

Jälkivalukolo tehdään reunapalkin valuun asetetun muotin avulla tai poraamalla aikaisintaan viikon kuluttua reunapalkin valusta.

Pylväs voidaan tukea pystysuoraan asentoon esim. käyttämällä kiiloja. Tällöin juotosvalu tehdään kahdessa osassa siten, että ensimmäinen valu keskeytetään 40 mm reunapalkin yläpintaa alemmalle tasolle. Juotosvalun saavutettua riittävän lujuuden poistetaan kiilat ja suoritetaan valu loppuun.

Jälkivalukolon valu kutistumattomalla juotoslaastilla, jonka puristuslujuus ≥35 N/mm² ja P–luku ≥P50.

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
1	Kaidepylväs	50x60x1390	S 235 J2

Harvan kaiteen paino liikuntajatkoksineen:
2–putkijohde 47,0 kg/m
Johde 240/6 56,3 kg/m (sis. alemman törmäysjohteen)

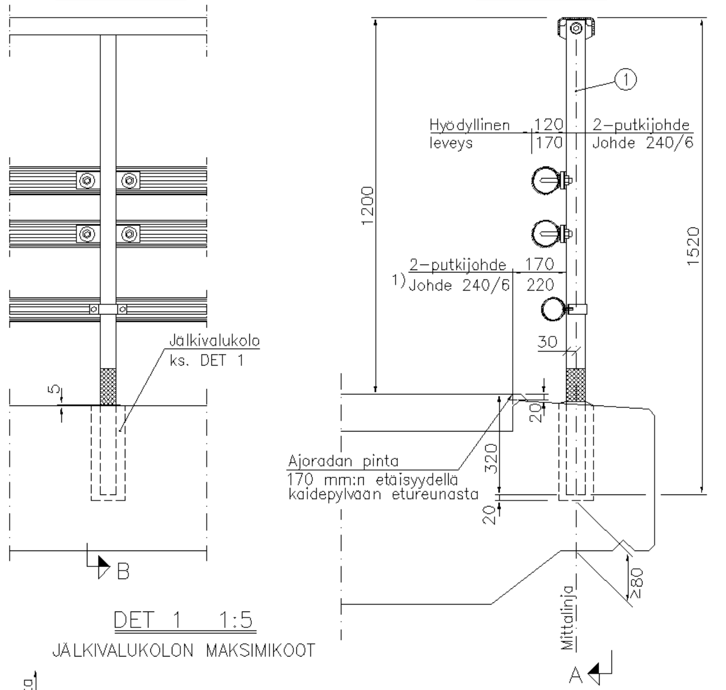
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

TIEH H2 SILLANKAIDE, LISÄPIIRUSTUS
KOLOKIINNITYS KORKEAAN REUNAPALKKIIN

A-Insinöörit Oy — Siltatekniikka, TIEHALLINTO

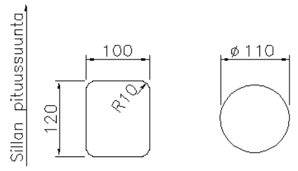
PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:10 1:5		PIIR. NRO	R15/DK H2–L1

FILE: DK H2–L1



DET 1 1:5

JÄLKIVALUKOLON MAKSIMIKOOT



1) Mitta 170 myös siltajohteella 240/6 varustetulla kaiteella sillan alittavan sähköistetyn rautatien yhteydessä käytettävän kaiteeseen integroidun kosketussuojaseinämän niin edellyttäessä.

Kaiteen asentamisessa noudatetaan Sillanrakentamisen yleisissä laatuvaatimuksissa (SYL 7) annettua ohjetta.

Kaidepylvään alapää pinnoitetaan kuumasinkityksen päälle tulevalla epoksimaalilla (80 μm) 400 mm:n matkalta.

Jälkivalukolo tehdään reunapalkin valuun asetetun muotin avulla tai poraamalla aikaisintaan viikon kuluttua reunapalkin valusta.

Pylväs voidaan tukea pystysuoraan asentoon esim. käyttämällä kiiloja. Tällöin valu tehdään kahdessa osassa siten, että ensimmäinen valu keskeytetään 40 mm reunapalkin yläpintaa alemmalle tasolle. Juotosvalun saavutettua riittävän lujuuden poistetaan kiilat ja suoritetaan valu loppuun.

Jälkivalukolon valu kutistumattomalla juotoslaastilla, jonka puristuslujuus ≥35 N/mm^2 ja P–luku ≥P50.

OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU
1	Kaidepylväs	50x60x1510 S 235 J2

Harvan kaiteen paino liikuntajatkoksineen (sis. alemman törmäysjohteen):
2–putkijohde 57,7 kg/m
Johde 240/6 57,7 kg/m

MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

TIEH H2 SILLANKAIDE, LISÄPIIRUSTUS
KOLOKIINNITYS MATALAAN REUNAPALKKIIN

INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:10 1:5		PIIR. NRO	R15/DK H2–L2

FILE: DK H2–L2

Appendix 2 Standard drawings of the Finnra H1 vehicle parapets:

- R15/DK H1-1 Frame, 2-pipe rail
- R15/DK H1-2 Bolted expansion joint of rail, 2-pipe rail
- R15/DK H1-3 Transition, 2-pipe rail
- R15/DK H1-4 Joint between rails on bridge and road, 2-pipe rail
- R15/DK H1-5 Frame, 230/5 rail
- R15/DK H1-6 Transition, 230/5 rail

Related pictures: standard drawings of the High vehicle parapet

www.tiehallinto.fi/sillat/tyyppipiirustukset/sillanosat/kaide/dk1.pdf

- R15/DK 1-1 Frame
- R15/DK 1-2 Welded expansion joint of handrail
- R15/DK 1-3 Middle rails
- R15/DK 1-4 Rail infill
- R15/DK 1-9 Bolt fixing to low edge beam
- R15/DK 1-10 Bolt fixing to high edge beam
- R15/DK 1-12 Bolted expansion joint of handrail

www.tiehallinto.fi/sillat/tyyppipiirustukset/sillanosat/kaide/dk3_4_ko.pdf

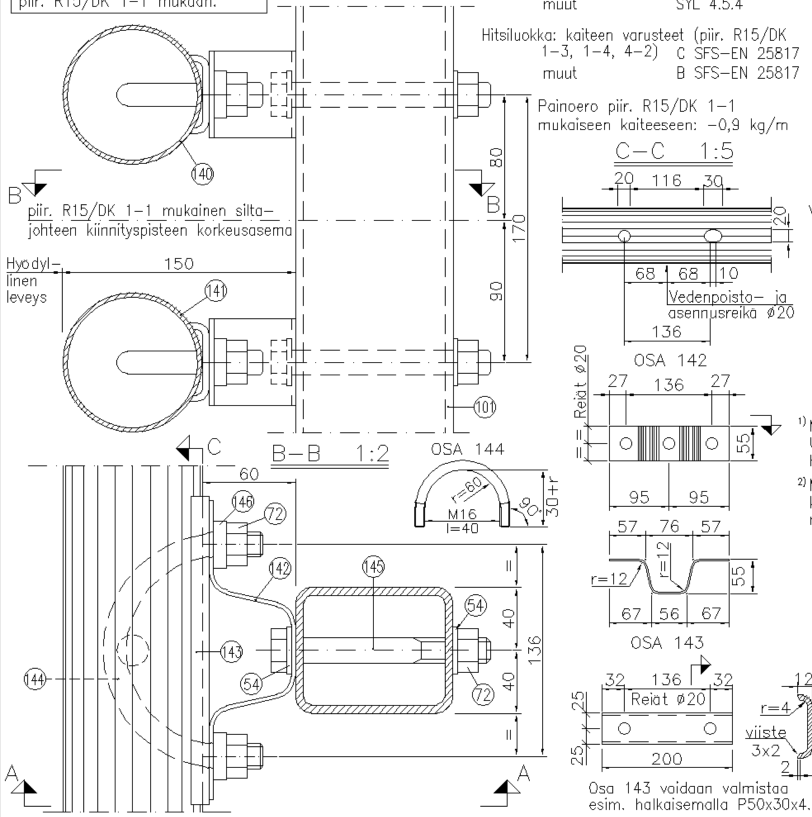
- R15/DK 4-2 Mesh infill
- Ko-2484 Joints of rail

Siltajohde loittokappaleineen tämän piirustuksen mukaan. Harvan kaiteen muu osa rungosta piir. R15/DK 1-1 mukaan.

Teräsosien kuumasinkitys: kaiteen varusteet (piir. R15/DK 1-3, 1-4, 4-2) ja kierteistetyt osat SFS-EN ISO 1461
muut SYL 4.5.4

Hitsiluokka: kaiteen varusteet (piir. R15/DK 1-3, 1-4, 4-2) C SFS-EN 25817
muut B SFS-EN 25817

Painoero piir. R15/DK 1-1 mukaiseen kaiteeseen: -0,9 kg/m



Osa 143 voidaan valmistaa esim. halkaisemalla P50x30x4.

OSA	NIMI	MITAT - STANDARDI	- TERÄSLAATU
101	Kaidepylväs	100x80x5	S 355 J2
140	Siltajohde	P88,9x3	S 355 J2
141	Siltajohde	P88,9x3	S 355 J2
142	Loittokappale	55x261x2,5	S 235 JR
143	Aluslaatta	U-12/50/12x4	S 355 J2
144	Panta	M16 L=274	S 355 J2
145	Kuusioruuvi	M16x130-8.8	SFS-ISO 4014
54	Aluslaatta	16-140 HV	SFS-ISO 7089
72	Kuusiomutteri	M16-8	SFS-ISO 4032
146	Aluslaatta	16-140 HV	DIN 7989

Osa 101: Reiät ø20. Ei reikiä piir. R15/DK 1-1 mukaisessa siltajohteen kiinnityspisteessä. Korjauskohteissa voidaan reikä sallia ellei tilaaja edellytä sen tulppaamista.

Viitepiirustukset:

Sillankaiteen runko	R15/DK 1-1
Yläjohteen hitsiliitosjatkos	R15/DK 1-2 (1
Yläjohteen ruuviliitosjatkos	R15/DK 1-12 (1
Siltajohteen jatkos	R15/DK H1-2
Tiheän kaiteen välijohteet	R15/DK 1-3
Kaiteen säleiköt (käyttö vain korjauskohteissa)	R15/DK 1-4
Korkea suojaverkko	R15/DK 4-2 (2
Sillankaiteen päättäminen	R15/DK H1-3
Silta- ja tiejohteen liitos	R15/DK H1-4
Pulttikiinnitys matalaan reunapalkkiin	R15/DK 1-9
Pulttikiinnitys korkeaan reunapalkkiin	R15/DK 1-10

1) Mikäli sillan suunnitelmassa on vaadittu yläjohdeprofiilin U-55/114/55x6 käyttöä, on yläjohteen jatkokset piir. R15/DK H2-2 ja niiden sijoittelu piir. R15/DK H2-1 mukaisia.

2) Mikäli sillan suunnitelmassa on vaadittu verkon #30x60/5 käyttöä, kiinnitetään se suojaverkkoelementin runkoon piir. R15/H2-5 mukaisesti.

MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

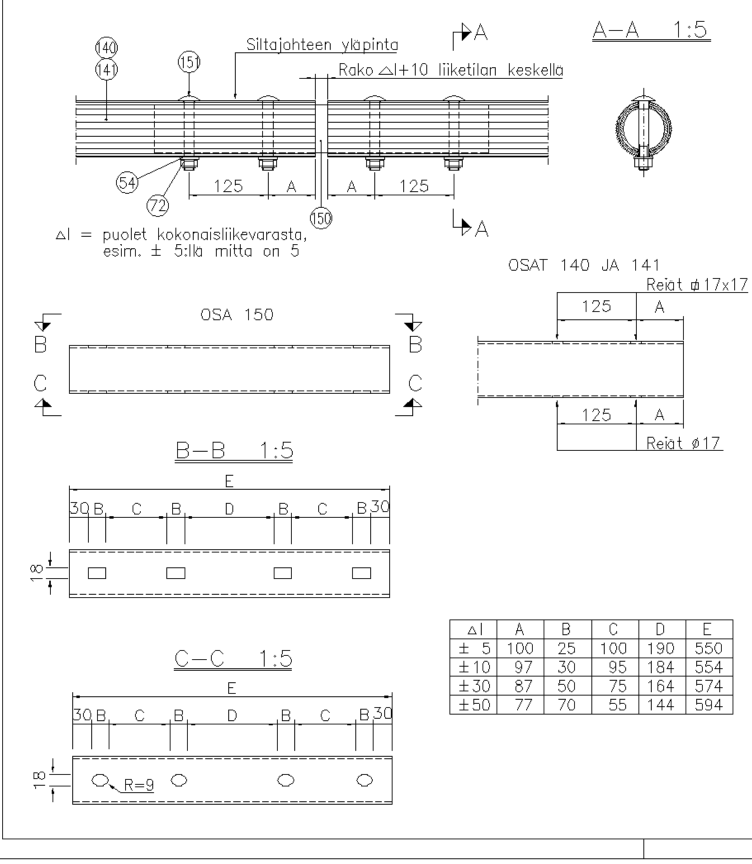
TIEH H1 SILLANKAIDE, 2-PUTKIJOHDE
HARVA KAIDE

INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:2 1:5		PIIR. NRO	R15/DK H1-1

FILE: DK H1-1

SILTAJOHTEEN JATKAMINEN 1:5



△l = puolet kokonaisliikevarasta, esim. ± 5:llä mitta on 5

△l	A	B	C	D	E
± 5	100	25	100	190	550
±10	97	30	95	184	554
±30	87	50	75	164	574
±50	77	70	55	144	594

OSA	NIMI	MITAT - STANDARDI	- TERÄSLAATU
140	Siltajohde	P88,9x3	S 355 J2
141	Siltajohde	P88,9x3	S 355 J2
72	Kuusiomutteri	M16-8	SFS-ISO 4032
54	Aluslaatta	16-140 HV	SFS-ISO 7089
150	Jatkoskappale	P76,1x4	S 355 J2
151	Lukkoruuvi	M16x110-8.8	SFS 2458

Osa 150: Voidaan tehdä myös putkesta P76,1x5 S355J2 piir. R15/DK H2-3 mukaisesti.

Teräsosien kuumasinkitys ja hitsiluokka: piir. R15/DK H1-1 mukaan

Jatkoksien sijoittelu piir. R15/DK H2-1 mukaan.

Liikevaran ollessa suurempi kuin ±50 mm annetaan sillan suunnitelmassa erikseen ohjeet liikuntajatkoksen tekemiseen.

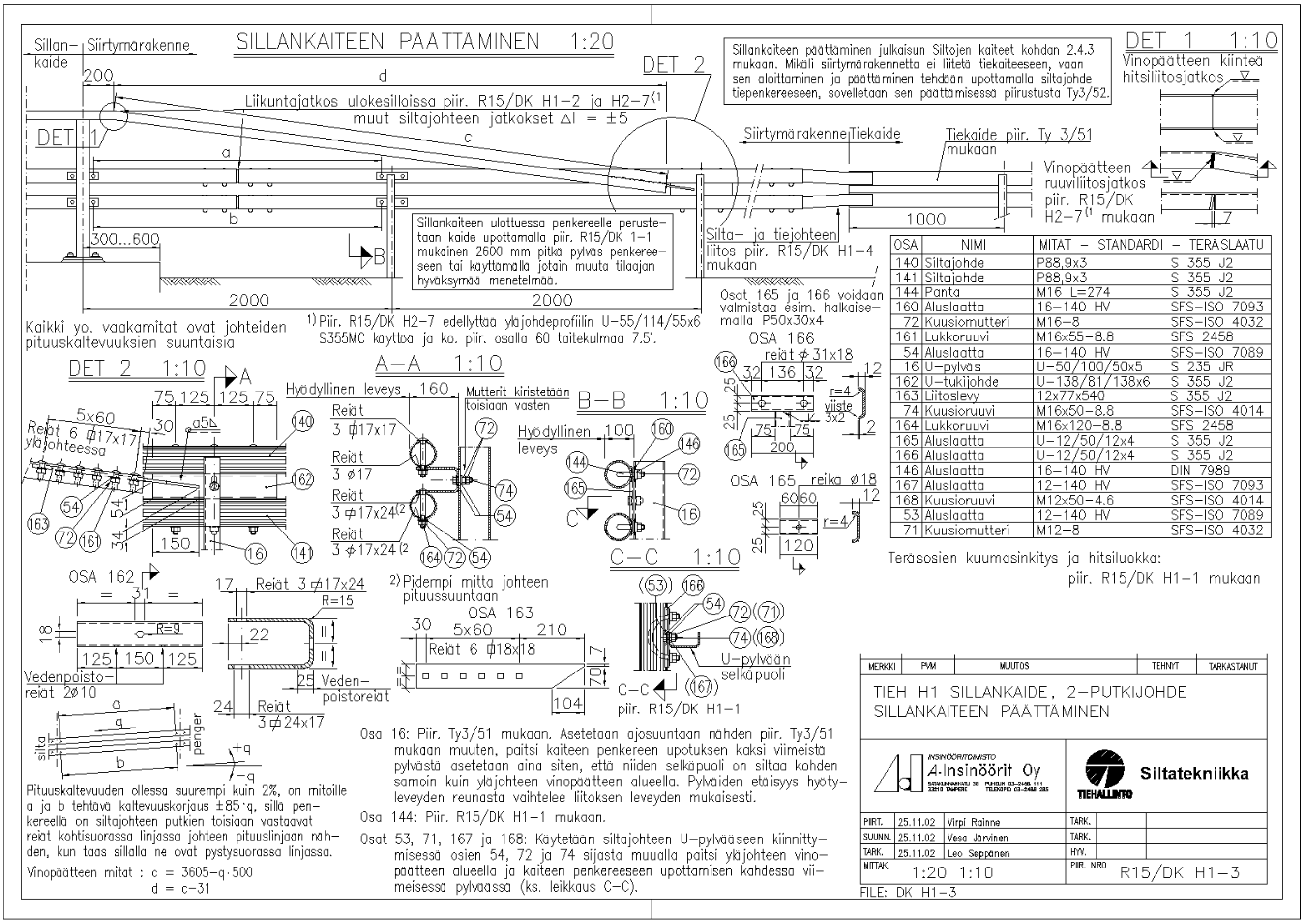
MERKKI	PVM	MUUTOS	TEHNYT	TARKASTANUT

TIEH H1 SILLANKAIDE, 2-PUTKIJOHDE
SILTAJOHTEEN RUUVILIITOSJATKOS

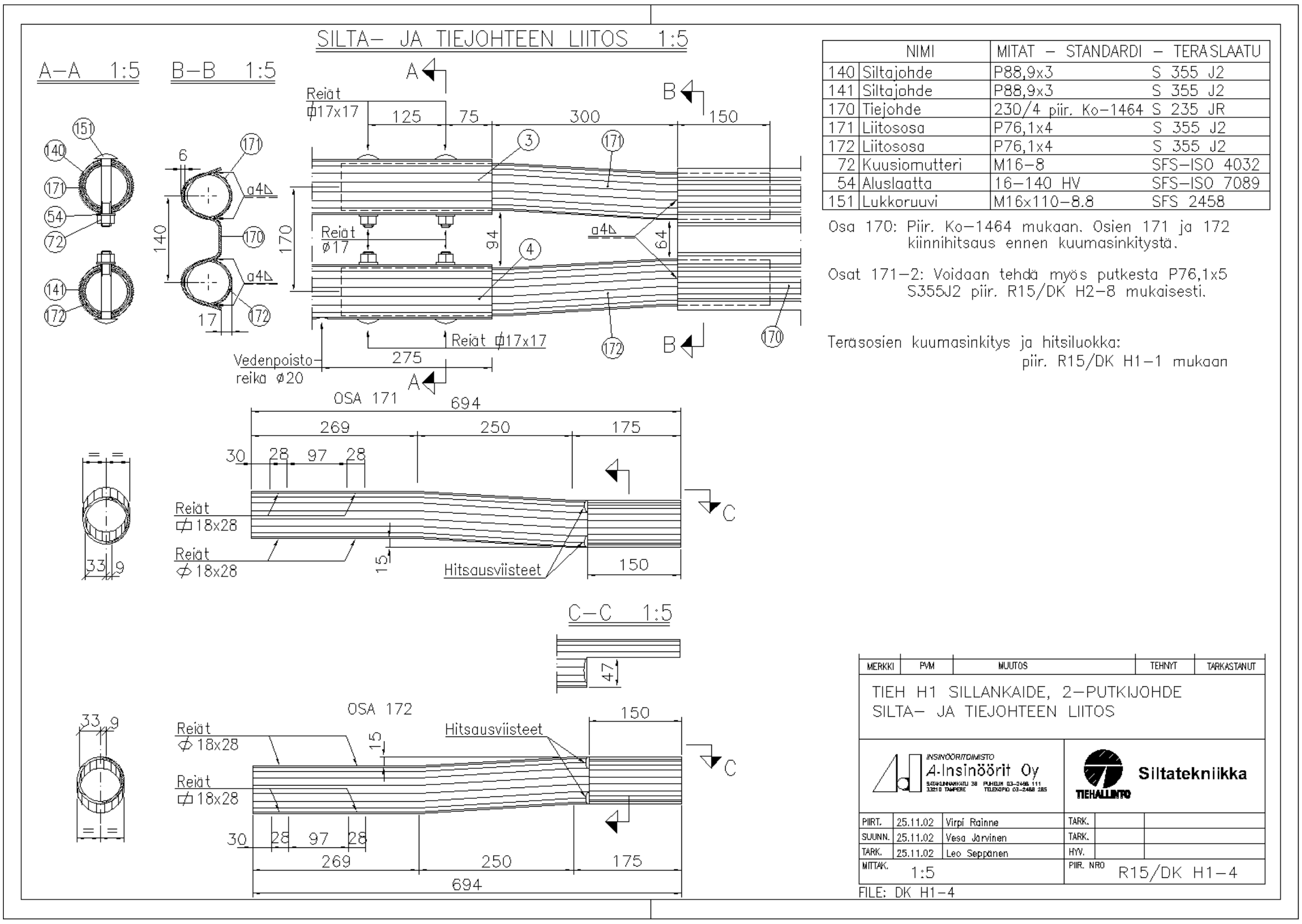
INSINÖÖRITOIMISTO A-Insinöörit Oy — Siltatekniikka — TIEHALLINTO

PIIRT.	25.11.02	Virpi Rainne	TARK.	
SUUNN.	25.11.02	Vesa Järvinen	TARK.	
TARK.	25.11.02	Leo Seppänen	HYV.	
MITTAK.	1:5		PIIR. NRO	R15/DK H1-2

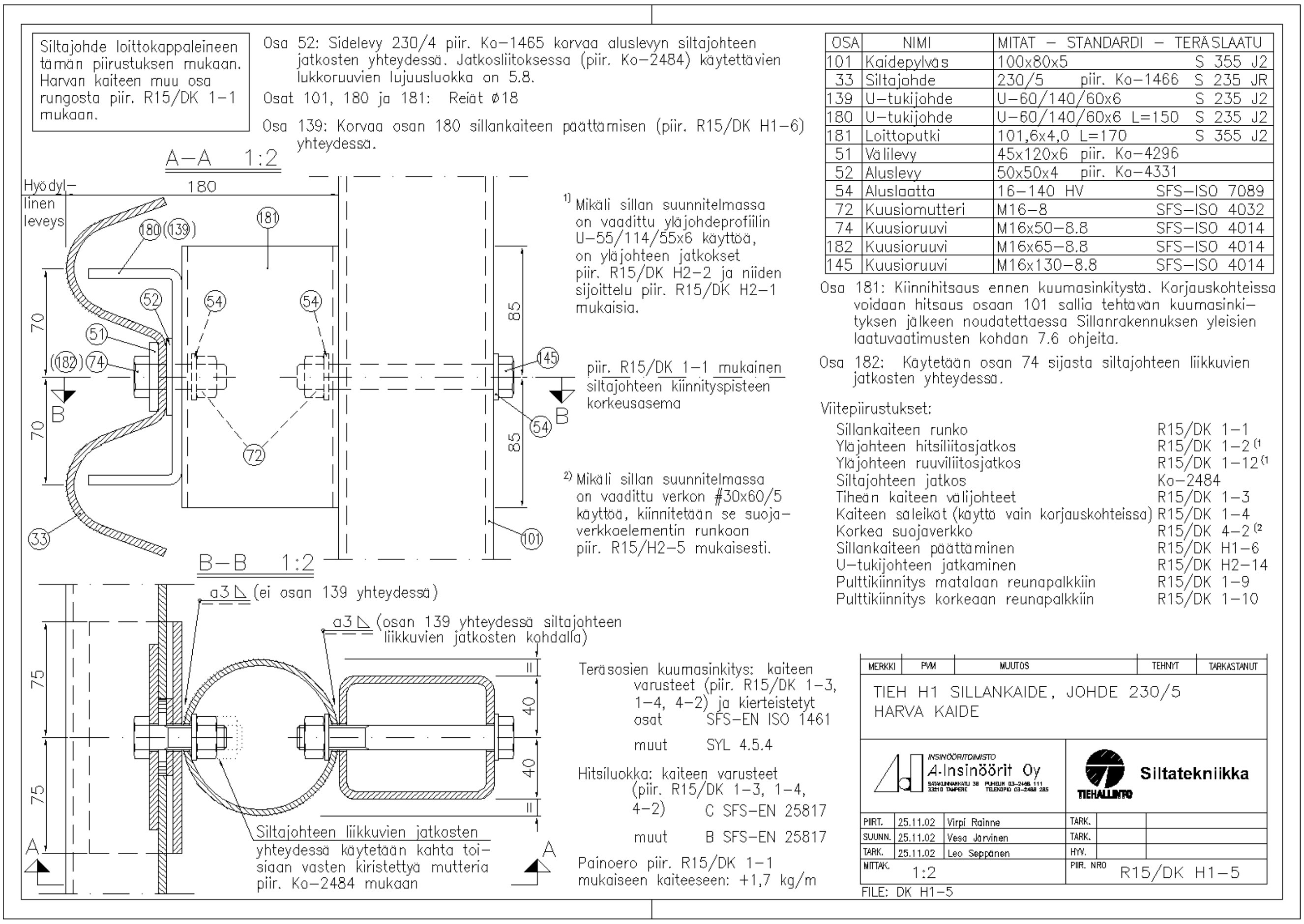
FILE: DK H1-2



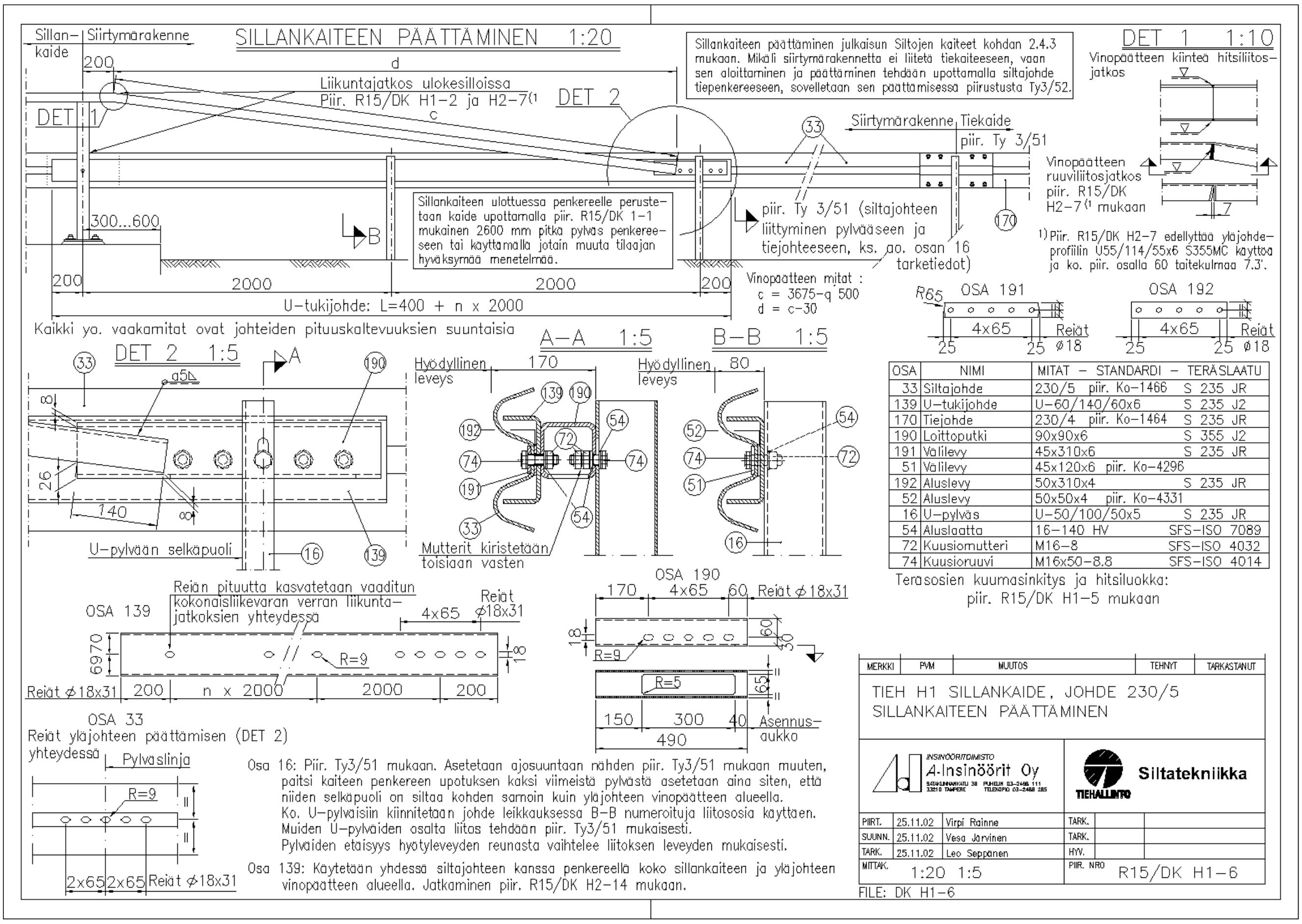
OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
140	Siltajohde	P88,9x3	S 355 J2
141	Siltajohde	P88,9x3	S 355 J2
144	Panta	M16 L=274	S 355 J2
160	Aluslaatta	16–140 HV	SFS-ISO 7093
72	Kuusiomutteri	M16–8	SFS-ISO 4032
161	Lukkoruuvi	M16x55–8.8	SFS 2458
54	Aluslaatta	16–140 HV	SFS-ISO 7089
16	U-pylväs	U-50/100/50x5	S 235 JR
162	U-tukijohde	U-138/81/138x6	S 355 J2
163	Liitoslevy	12x77x540	S 355 J2
74	Kuusioruuvi	M16x50–8.8	SFS-ISO 4014
164	Lukkoruuvi	M16x120–8.8	SFS 2458
165	Aluslaatta	U-12/50/12x4	S 355 J2
166	Aluslaatta	U-12/50/12x4	S 355 J2
146	Aluslaatta	16–140 HV	DIN 7989
167	Aluslaatta	12–140 HV	SFS-ISO 7093
168	Kuusioruuvi	M12x50–4.6	SFS-ISO 4014
53	Aluslaatta	12–140 HV	SFS-ISO 7089
71	Kuusiomutteri	M12–8	SFS-ISO 4032



	NIMI	MITAT – STANDARDI – TERÄSLAATU	
140	Siltajohde	P88,9x3	S 355 J2
141	Siltajohde	P88,9x3	S 355 J2
170	Tiejohde	230/4 piir. Ko-1464	S 235 JR
171	Liitososa	P76,1x4	S 355 J2
172	Liitososa	P76,1x4	S 355 J2
72	Kuusiomutteri	M16–8	SFS-ISO 4032
54	Aluslaatta	16–140 HV	SFS-ISO 7089
151	Lukkoruuvi	M16x110–8.8	SFS 2458



OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
101	Kaidepylväs	100x80x5	S 355 J2
33	Siltajohde	230/5 piir. Ko-1466	S 235 JR
139	U-tukijohde	U-60/140/60x6	S 235 J2
180	U-tukijohde	U-60/140/60x6 L=150	S 235 J2
181	Loittoputki	101,6x4,0 L=170	S 355 J2
51	Välilevy	45x120x6 piir. Ko-4296	
52	Aluslevy	50x50x4 piir. Ko-4331	
54	Aluslaatta	16-140 HV	SFS-ISO 7089
72	Kuusiomutteri	M16-8	SFS-ISO 4032
74	Kuusioruuvi	M16x50-8.8	SFS-ISO 4014
182	Kuusioruuvi	M16x65-8.8	SFS-ISO 4014
145	Kuusioruuvi	M16x130-8.8	SFS-ISO 4014



OSA	NIMI	MITAT – STANDARDI – TERÄSLAATU	
33	Siltajohde	230/5 piir. Ko-1466	S 235 JR
139	U-tukijohde	U-60/140/60x6	S 235 J2
170	Tiejohde	230/4 piir. Ko-1464	S 235 JR
190	Loittoputki	90x90x6	S 355 J2
191	Välilevy	45x310x6	S 235 JR
51	Välilevy	45x120x6 piir. Ko-4296	
192	Aluslevy	50x310x4	S 235 JR
52	Aluslevy	50x50x4 piir. Ko-4331	
16	U-pylväs	U-50/100/50x5	S 235 JR
54	Aluslaatta	16-140 HV	SFS-ISO 7089
72	Kuusiomutteri	M16-8	SFS-ISO 4032
74	Kuusioruuvi	M16x50-8.8	SFS-ISO 4014

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