# Ib6

## Ability of bridge parapets to withstand impact of vehicles

## Widerstandsfähigkeit von Brückengeländern beim Aufprall von Fahrzeugen

## Resistência das guardas de pontes submetidas aos choques de veículos

## Résistance des garde-corps de pont aux chocs de véhicules

ARNE RINKERT
*Civil Engineer, The Stockholm Harbour Board*
*Building Department*
Stockholm

***Introduction.***

Bridge parapets in Sweden have generally until lately been given dimensions suitable for a load considered to correspond to what might be expected to arise from press of people. Thus the Swedish Government specifications in force prescribe that bridge parapets shall have dimensions suitable for an evenly distributed load of 100 kg/m, acting in the most unfavourable direction for the parapet.

In Stockolm, however, it was found in the early thirties that bridge parapets ought also to constitute a certain obstacle against vehicles running off the bridge. It was therefore prescribed for bridges constructed shortly after 1932 by the Harbour Construction Departement of the Stockholm Harbour Board that the bridge parapets should be designed for a load of 250 kg/m. This load has since been increased to 350 kg/m. On several occasions, parapets designed for this load have shown that they can withstand impacts from private cars running into them.

Most of the bridges in Stockholm are provided with guard parapets at the outer edge of the footpath only. This type of parapet is shown in fig. 1 and consists of solid steel posts with the biggest dimension at right angles to the longitudinal direction of the parapet and firmly fixed in the heavily reinforced concrete edge beam of the bridge slab. At the top the posts are joined by a handrail of steel. Detachable gratings with vertical bars are suspended between the posts. The vertical bars have been provided to guard against children climbing over or through the parapet. The steel material is the Swedish quality St 37 S (yield point 2200 kg/cm²). The parapet has no hub railing intended to ward off the wheels of vehicles, but instead there is between the footpath and the roadway a curbstone, generally about 20 cm high.

On some of the newer bridges, which have separate footpaths, cycle tracks and roadways, such as the new Liljeholmen bridge, there has

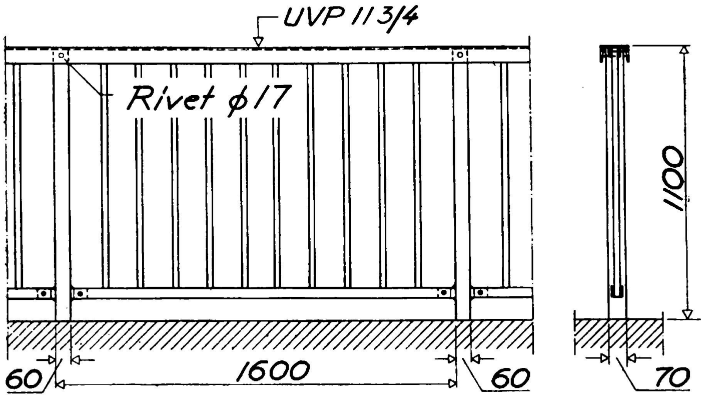


FIG. 1. Footpath parapet on the new Liljeholmen bridge in Stockolm. Weight 80 kg/m.

been introduced a guard parapet with hub railing between the roadway and the cycle track (fig. 2).

For highway bridges outside Stockholm, the Royal Board of Roads and Waterways made use of a standard parapet with a hub railing placed in the middle of the parapet about 35 cm above the level of the footpath (fig. 3).

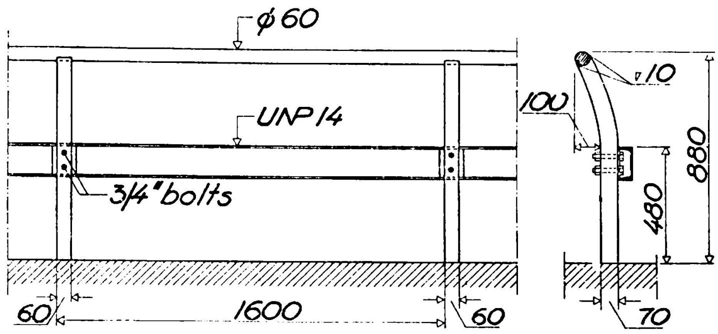


FIG. 2. Warding-off parapet between roadway and cycle track on the new Liljeholmen bridge. Weight 62 kg/m.

In 1948 a serious accident occurred on one of the older Stockholm bridges completed in 1928. After collision on the bridge with a motor truck an ordinary bus ran through the bridge parapet and sank in the water below, about ten passengers losing their lives. This bridge parapet had been designed according to the old standard, to take a load of 80 kg/m.

As a fully loaded modern bus has a weight of about 15 tons and the permissible speed for busses in Stockholm is 50 km/h, it was to be feared that not even the stronger parapets, as used on the newer bridges of the city, would be capable of arresting a bus running into them at an unfavourable angle of impact.

In view of this Stockholm City Authorities and the government Authorities decided in collaboration to have investigations carried out respecting the bearing capacity of bridge parapets as regards impact loads.

The purpose of the investigations was to test the bearing capacity of existing bridge parapet types, as well as to work out proposals for

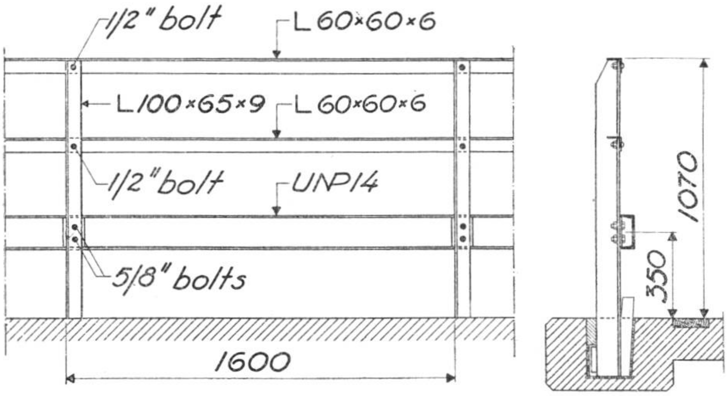


FIG. 3. Standard parapet of the Royal Board of Roads and Waterways. Weight 36 kg/m.

possible necessary strengthening of parapets on existing bridges and proposals for new types of parapets with the necessary bearing capacity for impact loads.

### *Model tests.*

To enable studies in principle to be made at reasonable cost on the design of the parapets with respect to their ability to take up heavy concentrated forces, there were first carried out some static and dynamic experiments with parapet models on the scale 1:10. It was found in

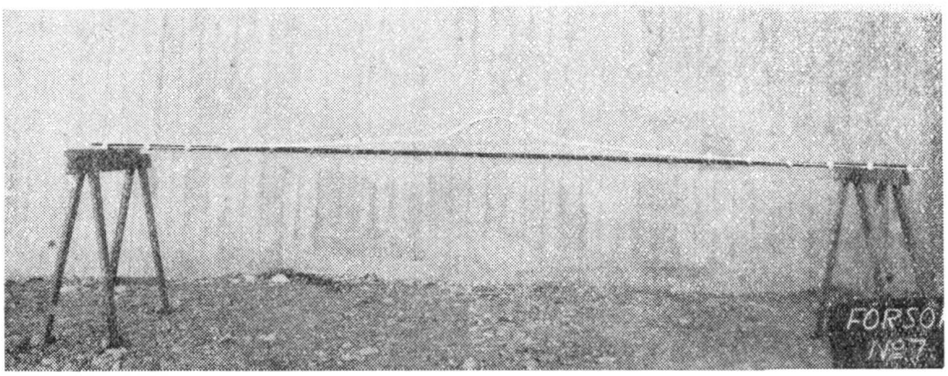


FIG. 4. Model parapet viewed from above after collision test. The railing is unbroken and dragged all the posts with it.

the model experiments that the ability of the handrail to take up purely tensile forces was of great importance. In this way, in fact, a considerable length of the parapet could be made to work actively in arresting the impact (fig. 4). One condition for ensuring this must be that the dilatation joints are designed to be able to transmit tensile forces.

Moreover it was found that if existing parapet types were given a handrail with an area of app. 50 cm², they could be expected to arrest a 15 ton bus, running at right angles to the parapet with a speed of at least 50 km/h.

It was not, however, possible fully to reproduce actual conditions with the model experiments. Thus the model bus was represented by a solid lump of iron which was made to swing like a pendulum against the parapet. The impact losses in the model experiments could not in this way be considered as corresponding to actual conditions. Nor could the hand-rail be made of the same section iron as in reality, and moreover it was not possible with the model to execute the same kind of joints as on real parapets. For these reasons it was considered necessary to carry out a number of experiments on a full scale.

***Full scale experiments.***

The experiments were carried out with superseded busses, which were loaded with concrete cubes. The total weight of a bus was equivalent to the weight of a bus full of passengers, i. e. about 15 tons in

FIG. 5. Slope provided with runway of wood. In the foreground, the parapet fixed in the concrete foundation.

all. The bus was allowed to coast unmanned down a ski-slope (fig. 5) which was provided with plank surfacing. The bus' steering gear was locked by a device that actuated the steering wheel with approximately the same force as a driver would have exercised.

The test parapets were set up below the slope in a strong concrete foundation anchored in rock. The parapet posts were firmly wedged in the foundation, so that they could easily be exchanged. The foundation was so arranged that the parapets could be set at angles of both 90° and 45° to the direction of running of the bus. That part of the foundation which was used for the 90° experiments was shaped at the collision point as a normal edge beam on footpath brackets. This enabled the bearing capacity of edge beams also to be tested. Each parapet had a length of 36 m, but as the end posts of the city test parapets were made stronger than the inner posts the test parapet corresponded to a parapet about 44 m with the posts all the same.

The speed of the bus just before the collision with the parapet was found by measuring with electric stop-watches the time taken to pass over a given stretch.

In addition, in most of the tests the bus speed was measured continuously throughout the run by means of ultrarapid film cameras, making about 1000 exposures a second. The camera was set up at one end of the parapet and so placed that the exposures were made at right angles to the direction of run. Further a few ordinary films were exposed at each test.

For reasons of economy, it was decided to carry out only one test with each type of parapet. A velocity was chosen therefore which would ensure breakage. The velocity corresponding to the energy of motion wasted was considered to be equal to the velocity at which breakage was just obtained in the parapet i. e. the breakage velocity.

Designating the breakage velocity as $V_{br}$, the velocity before collision as $V_a$ and the velocity after breakage has ocurred in the parapet as $V_p$, then $V_{br}$ is obtained from the equation

$$V_{br} = \sqrt{V_a^2 - V_p^2}$$

The equation should agree well, if the velocity on impact does not exceed the breakage velocity by too much.

Altogether thirteen tests were made, five applying to the parapet types of the Royal Board of Roads and Waterways and eight to those of the City of Stockholm.

***Test results.***

Account will only be given here of the more interesting tests.

The breakage velocity for the standard parapets of the Royal Board of Roads and Waterways (fig. 3) was found to be only about 17 km/h and for the footpath parapet of the new Liljeholmen bridge (fig. 1) about 20 km/h, both values applying to impact at right angles to the parapets.

In view of the above, the Royal Board of Roads and Waterways designed a stronger parapet (fig. 6), both posts and hand-rails being increased in dimensions. The hub railing in this design was moved upwards, so that its centre stood 40 cm above the bridge flooring.

With driving at right angles against this parapet the breakage velocity was 31 km/h, while with driving at an angle of 45° good warding off action was attained and the bus stopped at the proper side of the parapet, though it did touch the ground for an instant behind the parapet with one front wheel (fig. 7).

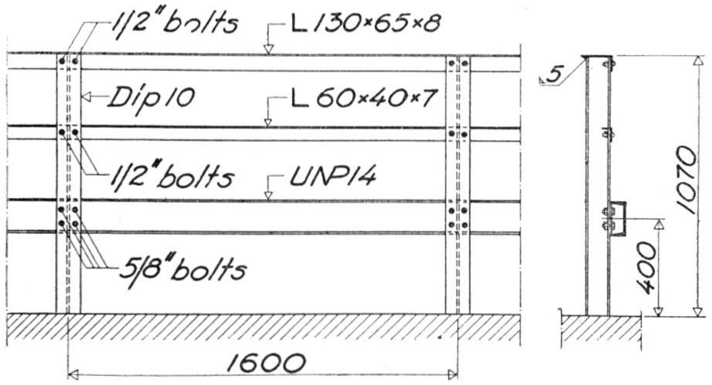


FIG. 6. Heavier parapet of the Royal Board of Roads and Waterways. Weight 51 kg/m.

The standard parapet (fig. 3) weighs 36 kg/m and the new parapet (fig. 6) 51 kg/m. By an increase of 40 % in the weight it has been possible to increase the motion energy absorbing capacity of the parapet a little over three times.

FIG. 7. Heavier parapet of the Royal Board of Roads and Waterways after the bus has run against at an angle of 45°. The bus has slid above the parapet and stopped on the right side, after one front wheel had touched the ground in front of the parapet for a moment.

As regards Stockholm City, as stated, it was a question both of strengthening existing types of parapet and of arriving at a new design, both to have adequate bearing capacity. The first type of parapet tested (fig. 1) — was strengthened with two steel bars, which were welded on the posts close to the handrail and had a total area of about 30 cm². Thus including the existing U-beam bars, the total bar area was 52.6 cm². The breakage velocity, in this case was greater than 45 km/h and the bus was heavily damaged (fig. 8).

FIG. 8. The Stockholm City's parapet reinforced by welded-on flat bars on a level with the hand-rail. Bus speed just before collision 45 km/h.

At the point of collision the U-bar was subjected to great bending moment in its stiffest direction. Therefore in new design efforts were made to give the bar such a shape thats its bending stiffness was as small as possible in the direction where the greatest bending might be expected.

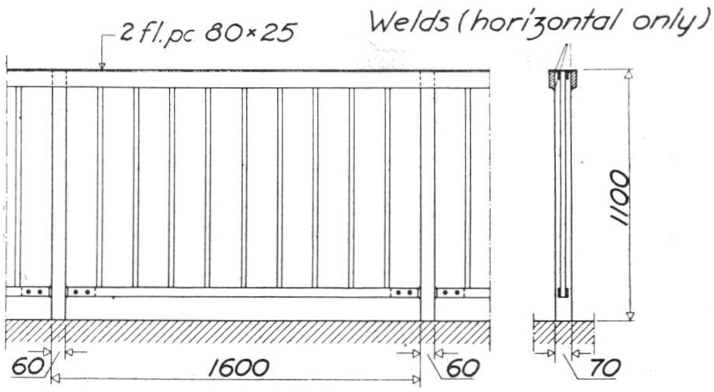


FIG. 9. The City's newly de-designed footpath parapet. Weight 93 kg/m.

The object was to ensure that the additional stresses on the rail due to bending would be small, so that the ability to absorb purely tensile forces would be increased.

In the newly designed parapet therefore the handrail consists of two flat bars set on edge with a total area of 40 cm² (fig. 9). The reason for employing two flat bars instead of one is chiefly because in that way the possibility of arranging the parapet's dilatation joints is substantially increased. On test, this parapet was found, with travelling

FIG. 10. The City's newly designed footpath parapet after impact at an angle of 45°. Bus speed just before collision 48 km/h.

at right angles against it, to hold against a velocity greater than 47 km/h. Rupture occurred in the flat bar located nearest the bus.

On test with 45° angle of impact the newly designed parapet was provided with detachable gratings in three middle divisions in order to obtain a certain amount of warding off effect. The velocity was 49 km/h and the bus was steered a little to the side, as may be seen in fig. 10. The parapet held without rupture.

As a final experiment, tests were made on warding off parapets of the type to be provided between the carriage-way and the cycle track (fig. 2). The direction of travel formed an angle of 45° with the parapet. The parapet held, but, as the beams of the bus chassis happened to be forced in between two posts and the bus was thus held, fast, only a slight warding off effect was obtained (fig. 11).

The newly designed footpath parapet (fig. 9) has a weight including gratings of 93 kg/m, whereas the old parapet (fig. 1) has a weight of 80 kg/m. By increasing the weight by only 17 % therefore, the parapet's ability to absorb energy of motion has been successfully increased about six times, possibly more, as the ski-slope height at the time did not provide a speed greater than 47 km/h.

In the above weights the gratings are included, amounting to 34 kg/m, which is rather much in view of the small benefit they give on inpact with heavy vehicles. On the other hand they should provide fairly good protection in respect of smaller vehicles. Moreover, the design of the gratings should, as stated earlier, be regarded as justified, owing to the protection it provides for pedestrians, particularly children. Aesthetically the design appears to be rather attractive.

The edge beam of concrete was found in the tests to be suitable. It is true that some of the reinforcement was torn away at the middle

FIG. 11. Warding off parapet between roadway and cycle track after impact at an angle of 45°. Bus speed just before collision 48 km/h.

post in some of the tests, but with the whole parapet collaborating, it is of no great importance if one of the posts is broken loose, as the load is carried over to the others.

***New Standards for parapets.***

In view of the experience obtained with the tests the parapets of Stockholm City bridges are to be strengthened so that they will be what may be called disaster-proof that is to say they can stop a 15-tons bus running at right angles to the parapet at a speed of 50 km/h. As a consequence *the existing footpath parapets* of later models are to be reinforced with flat bars welded to the posts at the level of the hand-rail. New bridges are to be provided with newly designed footpath parapets. The material is to be St 37 S, silica cemented Siemens Martin steel.

Where the platform of the bridge permits, however, *special guard of warding off parapets* will be arranged between roadway and cycle track or roadway and footpath. This guard parapet will then be made so strong that the vehicles can be arrested there, thus guarding pedistrians and cyclists against accidents. The guard parapet between roadway and cycle track, however, must be lower than the level of the cycle handlebars and thus not be made higher than about 0,9 m, reckoning from the cycle track level, whereas the footpath parapets have a height of 1,1 m.

With a lower parapet there is some risk of the parapet being bent forward and the vehicle simply driving over it. For this reason footpath parapets on bridges which are provided with guard parapets as well, are to be made stronger than would be required to resist the load of press of people. Then, with serious accident threatening, if the vehicle gets past the guard parapet it could finally be arrested by the footpath parapet. This will therefore be given dimensions estimated for impact from a 15 ton vehicle driving at 20 km/h at right angles to the parapet.

*Acknowledgements.*

In the Harbour Construction Department the investigation has been chiefly dealt with by the author under the direction of Mr M. Kullgren, Civil Engineer, Chief of Design, and assisted by Mr A. Jeppsson, Civil Engineer.

*Statement of main test data.*

Vehicle: Stockholm Tramways bus, type Volvo. Weight of bus empty app. 7 tons. Load of concrete cubes app. 7.4 tons. Total weight 14.4 tons.

Each parapet consists of 23 posts, about 1.60 m apart. Total length of parapet 35.2 m.

By «rupture», in the tables, is meant that the rail was broken through. By «passed» is meant that the bus in actual conditions would have gone off the bridge platform.

I. *Parapet types of the Royal Board of Roads and Waterways.*

Pole-railing attachment consists of bolting.

| Chronological numbering | Parapet type | Angle of attack | Posts | Top railing | Middle railing | Hub guard railing | Weight kg/m | Velocity km/m | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $V_a$ | $V_p$ | $V_{br}$ | |
| 2 | a | 90° | L 100×65×9 | L 60×60×6<br>A = 6.91 cm² | L 60×60×6<br>A = 6.91 cm² | UNP 14<br>A = 20.4 cm² | 36 | 30.6 | 25.6 | 16.8 | Passed (1) |
| 9 | a | 45° | » | » | » | » | » | 30 | – | – | (1 2) |
| 6 | b | 90° | Dip 10 | L 130×65×8<br>A = 15.09 mc² | L 60×40×7<br>A = 6.55 cm² | » | 51 | 35 | 16 | 31.1 | Passed (2) |
| 10 | b | 45° | » | » | » | » | » | 30 | – | – | |
| 11 | b | 45° | » | » | » | » | » | 48 | – | – | |

(1) Besides rupture in upper railing and middle railing

(2) The front wheels and about half the bus went through the parapet.
Material: Steel of merchant quality. (St 37)

## II. *Parapet types of the Port Authority.*

In the type c, d, $e_1$, $e_2$ and f the two end posts had dimensions 75×110
Grating weight 34 kg/m in addition, for types c, d, $e_1$, $e_2$ an f.

| Chronological numbering | Parapet type | Angle of attack | Posts | | Railings | | Post-trailing attachment | Weight kg/m | Velocity km/h | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dim. mm. | Material | Section | Material | | | $V_a$ | $V_p$ | $V_{br}$ | |
| 1 | c | 90° | 70 × 60 | St 44 s | UVP 11³/4<br>A = 22.6 cm² | St 37 | Rivets | 46 | 47.7 | 43 5 | 19.6 | Rupture<br>Passed |
| 3 | d | 90° | » | » | A = 22.6 cm² | » | Welds | 47 | 27.9 | 18.9 | 20.5 | Rupture<br>Passed |
| 4 | $e_1$ | 90° | » | » | UVP 11³/4<br>+ fl. pc. (¹)<br>30.8 cm²<br>$A_{tot}$ = 53.4 cm² | » | » | 71 | 31.4 | 0 | >31.4 | |
| 5 | $e_2$ | 90° | » | » | UVP 11³/4<br>+ fl. pc. (²)<br>30. cm²<br>$A_{tot}$ = 52.6 cm² (³) | » | » | 70 | 44.5 | 0 | >44.5 | |
| 7 | f | 90° | » | St 44 | 2 fl. pc. 80×25<br>A = 40 cm² | » | » | 59 | 35.6 | 0 | >35.6 | |
| 8 | f | 90° | » | » | A = 40 cm² | » | » | » | 47.7 | 0 | >47.7 | |
| 12 | f | 45° | » | » | A = 40 cm² | » | » | » | 49 | - | - | Gratings in the three middle sections |
| 13 | g | 45° | » | » | Round st. φ 60<br>+ UNP 14<br>$A_{tot}$ = 48.7 cm² | » | Welds and bolts | 62 | 50 | - | - | |

(¹) Flat piece 70×22 mm.
(²) Flat piece 75×20 mm.
(³) Ordered as St 37 S.

## SUMMARY

Bridge parapets were originally designed for a load considered to be equivalent to what might be thought to arise from press of people. Consequently the Swedish government specifications prescribed that bridge parapets should be designed for an evenly distributed load of 100 kg/m, acting on the top of the parapet in the most unfavourable direction for the parapet.

In Stockholm, however, the realisation that bridge parapets might also require to constitute an obstacle for at least small vehicles running off the bridge had as long as 20 years ago led to an increase of the above fictitious load. Most of the bridges built after 1930 therefore have parapets which are dimensioned for a load of 250 kg/m. For bridges built after 1940 this load has been raised to 350 kg/m.

In consequence of a serious accident on one of Stockholm's older bridges, the Stockolm Harbour Board has worked out proposals for so-called disaster-proof bridge parapets. A parapet is considered disaster--proof if it can arrest the heaviest bus in service — app. 15 tons — when driven at right angles to the parapet with a speed of 50 km/h. This speed is the highest permitted for busses in Stockholm.

As basis for the proposals a number of collision tests both on model and on full scale have been made. The bearing ability stated above is obtained by letting a great length of the parapet collaborate in arresting the impact. The collaboration is attained by giving the hand-rail such a section that it is capable of absorbing great tensile forces. An area of 40 $cm^2$ for the hand-rail was found sufficient if the material is St 37 S. In addition the section should be so selected that supplementary stresses due to bending — mainly around a vertical axis — will be as small as possible. Further the dilatation joints must be so formed that they are capable of absorbing the same tensile force as the handrail.

The new type of parapet weighs only 17 % more than those hitherto in use. Nevertheless, the bearing capacity on collision is substantially higher, the energy of motion which the parapet can absorb is about six times greater than the corresponding value for the types of parapet usual up to now.

## ZUSAMMENFASSUNG

Brückengeländer wurden ursprünglich für eine Last bemessen, die in dieser Grösse durch ein Menschengedränge entstehen konnte. Daher verlangten die schwedischen Regierungsvorschriften, dass Brückengeländer einem am obern Ende in der ungünstigsten Richtung angreifenden, gleichmässig verteilten Druck von 100 kg/m widerstehen mussten.

In Stockholm dagegen hatte bereits vor 20 Jahren der Umstand,

dass Brückengeländer auch ein Hindernis wenigstens für kleinere, über den Brückenrand hinausfahrende Fahrzeuge bilden konnten, zu einer Vergrösserung der erwähnten angenommenen Belastung geführt. Die meisten der nach 1930 erbauten Brücken besitzen deshalb Geländer für eine Last von 250 kg/m, welche für nach 1940 erbaute Brücken sogar auf 350 kg/m erhöht wurde.

Veranlasst durch einen schweren Unfall auf einer der älteren Stockholmer Brücken hat die Stockholmer Hafenbehörde Vorschläge für sogenannte unfallsichere Brückengeländer ausgearbeitet. Ein Geländer wird als unfallsicher betrachtet, wenn es dem schwersten in Betrieb stehenden Autobus (nahezu 15 Tonnen), der mit einer Geschwindigkeit von 50 km/h rechtwinklig gegen das Geländer fährt, widerstehen kann. Diese Geschwindigkeit darf in Stockholm durch Autobusse nicht überschritten werden.

Als Grundlage für die Vorschläge dienten eine Anzahl Aufprallversuche an Modellen und in natürlicher Grösse. Die oben erwähnte Tragfähigkeit lässt sich durch das Zusammenwirken eines langen Geländerstücks für das Auffangen des Stosses erreichen. Für das Zusammenwirken benötigt die Handschiene einen Querschnitt, der grosse Zugkräfte aufnehmen kann. Eine Fläche von 40 $cm^2$ genügt hierfür bei Verwendung von St 37 S. Dazu sollte der Querschitt so gewählt werden, dass zusätzliche Biegespannungen, hauptsächlich bezüglich einer vertikalen Achse, so klein als möglich ausfallen. Weiter müssen die Dilatationsfugen die gleichen Zugkräfte wie die Handschiene übernehmen können.

Der neue Geländertyp wiegt nur 17 % mehr als der bisher übliche. Trotzdem ist die Tragfähigkeit beim Aufprall wesentlich höher, kann doch dieses Geländer einen sechs mal höhern Wert an Bewegungsenergie aufnehmen als das bisher benutzte.

## RESUMO

As guardas das pontes eram originalmente calculadas para resistir a uma carga equivalente à que poderia causar uma multidão. O regulamento oficial sueco especificava portanto que as guardas das pontes deviam calcular-se para uma carga uniformemente distribuída de 100 kg/m, aplicada no topo do parapeito na direcção mais desfavorável em relação à guarda.

Em Estocolmo no entanto, há já vinte anos que se tinha aumentado essa carga fictícia considerando que as guardas deveriam, pelo menos, também poder constituir um obstáculo para pequenos veículos galgando a ponte. As guardas da maioria das pontes construídas depois de 1930 foram portanto calculadas para uma carga de 250 kg/m. Nas pontes construídas depois de 1940 essa carga passou para 350 kg/m.

Em consequência de um grave acidente ocorrido numa das pontes mais antigas de Estocolmo, a Administração do Porto dessa cidade estudou diversos tipos de guardas de ponte à prova de desastres. Uma guarda é considerada à prova de desastres se é capaz de resistir a um

autocarro dos mais pesados em serviço — 15 toneladas aproximadamente — dirigido perpendicularmente ao parapeito a uma velocidade de 50 km/h, o que corresponde ao máximo autorizado para os autocarros em Estocolmo.

Fizeram-se uma série de ensaios de colisão em modelo reduzido e em escala natural para servirem de base aos referidos estudos. A capacidade de carga é obtida interessando um grande comprimento de guarda à resistência ao choque. Para isso deu-se ao parapeito uma secção capaz de absorver grandes forças de tracção. Uma secção de 40 cm² de aço St 37 S foi considerada suficiente. A secção também deve ser escolhida de modo que as tensões suplementares devidas à flexão, principalmente à volta de um eixo vertical, sejam as mais pequenas possíveis. As juntas de dilatação devem poder absorver a mesma força de tracção que o parapeito.

O novo tipo de guarda pesa apenas 17 % mais do que os empregados até agora. No entanto a capacidade de carga em caso de colisão é bastante mais importante, sendo a energia de movimento que a guarda pode absorver aproximadamente seis vezes maior do que o valor correspondente aos tipos de guarda em uso até agora.

## RÉSUMÉ

Les garde-corps de ponts étaient calculés à l'origine pour une charge fictive équivalente à celle que pourrait produire la poussée de la foule. Le règlement Suedois spécifiait donc que les garde-corps devraient être calculés pour une charge uniforme de 100 kg/m appliquée le long du parapet et agissant dans la direction la plus défavorable par rapport au garde-corps.

A Stockholm néanmoins, il y a 20 ans que cette charge fictive avait été augmentée pour tenir compte du fait que les garde-corps devraient être capables de constituer un obstacle, au moins pour de petits véhicules tendant à quitter le pont. La plupart des ponts construits après 1930 sont donc munis de garde-corps dimensionnés pour une charge de 250 kg/m. Dans les ponts construits après 1940 cette charge est de 350 kg/m.

A la suite d'un grave accident survenu sur l'un des ponts les plus anciens de Stockholm, l'Administration du Port de cette ville a étudié une série de garde-corps à l'épreuve des accidents. Un garde-corps est dit à l'épreuve des accidents, s'il est capable d'arrêter l'autobus le plus lourd en service — environ 15 tonnes — lancé normalement au parapet à une vitesse de 50 km/h, vitesse limite des autobus à Stockholm.

Une série d'essais sur modèle réduit et en vraie grandeur ont été effectués pour servir de base à ces études. La capacité de charge est obtenue en intéressant une grande longueur de garde-corps à la résistance aux chocs. Ceci est obtenu en donnant au parapet une section capable d'absorber de grands efforts de traction. Une section de 40 cm² en acier St 37 S a été reconnue comme suffisante. La section doit encore avoir

une forme telle que les contraintes suplémentaires dues à la flexion, surtout autour d'un axe vertical, soit aussi faibles que possible. De plus, les joints de dilatation doivent être conçus de manière à pouvoir transmettre le même effort de traction que le parapet lui-même.

Le nouveau type de garde-corps ne pèse que 17 % de plus que les anciens modèles. Néanmoins sa capacité de charge en cas de collision est substantiellement plus grande, l'énergie de mouvement que le garde-corps peut absorber étant à peu près six fois plus grande que la valeur correspondante dans les types de parapet en usage jusqu'ici.