Numerical simulation and full-scale field testing of steel parapet railing under impact of heavy truck loads – comparative study

S K Che Osmi, A Rosdi, H Husen, S Sojipto, N A Misnon and F H Khairuddin

Department of Civil Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Sungai Besi, 57000 Kuala Lumpur, Malaysia

E-mail: sitikhadijah@upnm.edu.my

Abstract. Bridge parapet is one the most critical part of the bridge superstructure, which functions as a safety feature during accident or collision at the edges of the bridge. For steel parapet railing, complete full-scale field testing needs to be carried out before installation of new parapet railing. Field testing not only expensive but also very time-consuming for preparation and testing works. In this study, a comparison between the results of an actual field test and numerical simulation works was investigated. The chosen 3S two-beam steel parapet had passed the field testing conducted by the Korean Transportation Safety Agency (KOTSA). For comparison, the performance of the steel parapet selected railing was simulated under impact loading of heavy trucks, whereby no passenger car test was conducted. The parapet railing design was modelled and simulated using the SolidWorks and the NASTRAN/PATRAN software, respectively. Five case studies were derived to ensure the reliability and accuracy of the obtained results. Case 3 recorded the lowest difference percentage of 3.6% for the maximum deformation of the parapet railing. However, other case study recorded more than 10% discrepancy of the maximum deformation (i.e. Case 1, 2, 4 and 5). It can be concluded that Case 3 as the right position where the impact load exerted during the field testing. These results proved that the numerical simulation results provide a reliable result for testing the quality of the parapet railing with a minimum cost and time required, consequently, tackle the shortcomings of the field testing.

1. Introduction

Bridge is a structure that builds on purpose to connect two places that separated by natural or human-made obstacles such as rivers, sea, hilly part, and building. One of the most crucial structural components of the bridge superstructure is bridge parapet, which located at both longitudinal edges of the bridge and functions as a safety feature during an accident or collision on the bridge. During an accident, the parapet will act as a barrier to contain vehicle or road users within the bridge width and, consequently, minimise the effect of the secondary accident due to collision of the vehicle onto the parapet. Three most common types of bridge parapet are steel, concrete, and composite (i.e. combination of steel and concrete parapet). Figure 1 shows the position of steel parapet railing on the bridge structure.

Accident on the roadway is an unpredictable event which can occur anytime due to many factors such as speeding. Many safety features were invented to minimise the effect of the accident on road users and vehicles. The safety of the road user and vehicles on the bridge is vital and should be taken into consideration in designing bridges. In British code of practices (e.g. [1-3]), the parapets are
constructed to provide specified levels of containment to limit penetration by errant vehicles and to protect highway users by redirecting the errant vehicles with minimum deceleration forces on to a path as close as possible to the line of the parapet [1].

Therefore, for steel parapet railing, complete full-scale field testing needs to be carried out before installation of new parapet railing as required by national or international standards and code of practices [1-5]. However, full-scale field testing not only expensive but also very time-consuming, especially for preparation and testing works. Besides, most of the field testing was not conducted in Malaysia because the expertise and complete facilities of the testing are not available. The steel parapet design usually imported, whereby the standard and testing requirements need to be performed at the origin country of the manufacturer. All of these problems may delay the approval and installation process and also adding more cost to the total expenditure.

![Figure 1. Position of steel parapet railing on the bridge structure.](image)

Along this line, in this study, a comparison between the results of actual full-scale field tests and numerical simulation works was investigated. Numerical simulation was chosen due to the ability of this method to imitate a real case presentation and enable to produce faster results with a lower cost of operation [6]. The outcome of this study is expected to provide a solution to tackles the shortcoming of full-scale field testing.

2. Full-scale field testing of steel parapet railing
According to BS 6779: Part 1 (1998), during the collision, the vehicle would typically hit the parapet at an angle, not more than 20 degrees [1]. Similarly, the National Cooperative Highway Research Program (NCHRP) Report 350 (1992) [4] suggested that the vehicle the angle of incidence is between 15 degrees to 25 degrees. Several factors need to be taken into consideration when investigating the collision of a vehicle to the bridge parapet, such as the strength of the parapet, speed of the vehicle, angle of incidence, the weight of the vehicle, and height of the centre of gravity of the vehicle.

In particular, the Highway Department (HyD) of Hong Kong [5] proposed four types of vehicle collisions onto parapet (Figure 2). First, the vehicle collides at its front corner, which is usually at the vehicle bumper. Second, the vehicle experienced lateral scrapping of its side body against the parapet. In type three collision, the vehicle collides its rear corner with the parapet. Finally, type four, the vehicle re-enters onto bridge carriageway. As shown in Figure 2, the angle of incidence (ϕ) and the exit angle (α) are two crucial angles in determining the impact of the collision on the vehicles.
2.1. Full-scale field test requirements
Any design of parapet should undergo a complimentary field testing to test the effectiveness and strength of that parapet design [1-5]. Table 1 summarises six test levels for field testing of steel parapet railing, which depending on vehicle size and speed as suggested by the NCHRP [4]. Before performing the field test, several requirements should be followed as required by standard and code of practices (e.g. [1-3]).

A minimum of 30m length of steel parapet or not less than ten standard panels are required to field testing. The testing area shall be a flat surface area similar to a normal highway standard and must be sufficient in size to enable the test vehicle to accelerate according to the required speed. All main bolts connecting posts to rails and rail joints shall remain in position as stated in Clause 10.1.2.3, BS 6779 [1]. From the field test, the maximum penetration and deformation of the vehicle during impact, and description of the damage to parapet will be registered.

| Test Level | Impact Speed | Type of Vehicle |
|------------|--------------|-----------------|
| TL-1       | 50 km/h      | 820 kg saloon car, 2000 kg pickup car |
| TL-2       | 70 km/h      | 820 kg saloon car, 2000 kg pickup car |
| TL-3       | 100 km/h     | 820 kg saloon car, 2000 kg pickup car |
| TL-4       | 100 km/h     | 820 kg saloon car, 2000 kg pickup car, 8000 single unit truck |
| TL-5       | 100 km/h     | 820 kg saloon car, 2000 kg pickup car, 36000 kg tractor trailer |
| TL-6       | 100 km/h     | 820 kg saloon car, 2000 kg pickup car, 36000 kg tanker truck |

2.2. Full-scale field testing results
Field test report on 3S Railing System two-beam [7] with a dimension of 900mm (height) x 250mm (width) x 3000 (long) was used in this study. This bridge parapet railing has been installed to replace the existing parapet at KM 456.3, PLUS Expressway. The parapet design has successfully undergone TL-4 (refer Table 1) test level conducted by the Korean Transportation Safety Agency (KOTSA) [7]. Under KOTSA, the parapet railing underwent two types of vehicle impact load tests, i.e., heavy truck test and a passenger car test. The requirement is stated in the Manual of Design Guidelines of Longitudinal Traffic Barrier [8] whereby, all types of steel parapet railing in the major road in Malaysia must at least achieve a minimum standard of TL-3.

In the TL4, the field testing was conducted using 1.3-ton passenger car at 20 degrees of impact angle with a speed of 81.7 km/h and 14-ton truck at 15 degrees of impact angle with a speed of 67.2 km/h. The test result of field testing was divided into three evaluation factors; (i) structural adequacy of safety...
barrier, (ii) test vehicle behaviour and (iii) prevention of scattering structure components. It is noted that the 3S railing systems are adequate to withstand TL-4 impact condition. The field testing result is tabulated in Table 2.

Table 2. Field testing result on heavy truck [7].

| Evaluation Factors                  | Criteria                                                                 | Test Result                                      |
|-------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------|
| Structural adequacy of safety barriers | The safety barrier shall contain and redirect the vehicle without a complete break of the principal longitudinal element of the system | Vehicle contained and smoothly redirected         |
|                                     | Maximum deformation shall be less than 1.1 m                             | Maximum deformation is 0.74 m (740mm)             |
| Test vehicle behaviour              | Exit speed should be more than 60% of impact angle                       | 69.8% (46.9 km/h) of impact speed                |
|                                     | Exit angle should be less than 60% of impact angle                       | 38.0% (5.7°) of impact load                      |
|                                     | The vehicle should remain upright during and after collision             | Be upright                                       |
| Prevention of scattering structure component | The scattering of the structural component shall not injure the passenger or another person on the road | No scattering of structural component             |

3. Methodology

This study aims to compare the results of the full-scale field testing and the numerical simulation of the 3S two-beam system of steel parapet railing. The methodology of this study is divided into six steps as shown in Figure 3.

Figure 3. Research framework.
3.1. Collection Data of Field Testing
The structural drawing and results of the field testing conducted by KOTSA [7] for 3S steel parapet railing were given by Perunding ZAR Sdn. Bhd. The company is a Malaysian consultant company which expert in designing bridge projects in Malaysia. All of the information stated in the drawing and test results are required in performing the numerical simulation.

3.2. Numerical modelling
In SolidWorks, the actual steel parapet design was remodelled similar to the detail structural drawing parapet of the 3S railing system two-beam type (3S H900 x W250 x L3000). The 3D model was first generated in the SolidWorks software, then was transferred to the NASTRAN/PATRAN software for simulation purposes. The parapet was supported by the post with 900 mm from ground level. The parapet design consists of two beams of steel parapet railing which attached at upper and lower sides of the post. The lower beam is designed to cater the impact of the small vehicle while the upper beam is designed to cater the impact load from heavy vehicle.

The characteristic steel strength adopted in the numerical model in the SolidWorks software is similar to the actual steel strength used by a 3S railing system, i.e. tensile strength of 275 N/mm² and yield strength of 351 N/mm² [7]. The parapet, which has the 30 meters long was modelled. However, the load of the heavy truck was assumed to be imposed at 6 meters of the intermediate span of the parapet in numerical simulation. Figure 4(a) below shows the full-scale model of the parapet design with a total length of 30m, while Figure 4(b) shows the 6m span (i.e. two panels of the parapet design that used for the simulation purposes.

![Parapet Design](image)

(a) 30m length of the parapet

(b) 6m intermediate span of parapet

**Figure 4.** Overall numerical models of the 3S two-beam parapet railing (All dimension is not drawn to scale).

Each of the parapet railing panels has a length of 3000 mm measured from post to post. This is the standard requirement stated in the NCHR Report 350: 1992, Clause 2.3.2.1 [2], whereby the parapet railing must be at least 30 meters in length or minimum 10 panels of the parapet design for the field testing purposes. Figure 5 shows the overall view of a numerical model of 3S two-beam steel parapet railing, which consists of the overall design, location, and dimension of the parapet post, beam, reinforced plate, upper railing, and lower railing.
3.3. Numerical simulation of parapet model

The impact of the heavy truck on the parapet had been simulated in NASTRAN/PATRAN. Impact loading of the heavy truck was applied to the upper part of the railing. In the field testing results, the exact part or location of the impact applied to the parapet was not given. Therefore, in the numerical simulation, a total of five cases study was derived to determine the actual location of the applied load on the parapet railing. As refers to Figure 6, for Case 1 and Case 5, the impact load with a 15-degree angle of incidence was applied at both left and right ends of the parapet panel, respectively. However, for Case 2 and Case 4, the similar load impacts were applied at the centre of the first and second of the parapet panel. Meanwhile, for Case 3, the impact load was applied at the centre post of the parapet model. Figure 6 shows five cases study which refers to the location of the applied load applied in numerical simulation.

Based on the input value given in the field testing report, the numerical models of the 3S steel parapet railing were simulated to receive impact loading of 79.65kN at 15 degrees angle of incidence, from a
14-ton weight of heavy truck at speed of 67.2 km/h. The performance of the parapet railing under given impact loads was investigated due to maximum deformation of parapet panel.

4. Results and discussion

For numerical simulation, the impact of 79.65 kN heavy truck loads were applied at 15 degrees angle of incidence for five different case study stated in previous section. It can be seen that the highest magnitude of maximum deformation (\(\Delta_{\text{Max}}\)) of 1590 mm was recorded when the heavy truck load applied at the centre of first-panel parapet (i.e. Case 2). Then followed by Case 4 (i.e. 1410mm), Case 1 (i.e. 997mm), Case 5 (i.e. 907mm), and the lowest magnitude of maximum deformation of 767mm was experienced in Case 3 condition.

The comparison between numerical simulation and field testing results are summarised in Table 3 below. According to the field testing, the maximum deformation of the parapet railing is 740 mm. However, based on numerical simulation, among of the five cases, Case 3 (i.e. \(\Delta_{\text{Max}} = 767\) mm) provide better agreement with the field testing result, whereby the percentage of difference is 3.6%. The value is the lowest percentage of deformation obtained by numerical simulation, whereby the highest maximum deformation was estimated to occur when the heavy truck hit the centre of parapet panel (i.e. Case 2 and Case 4). The numerical results for Case 1 to Case 5 are depicted in Figure 7 to Figure 11, respectively.

| Cases | Specific location          | Numerical result Deformation, \(\Delta_{\text{Max}}\) (mm) | Field testing | % Difference |
|-------|---------------------------|----------------------------------------------------------|---------------|--------------|
| 1     | Left end post             | 997                                                      | 740 (no actual position is stated in the field testing report) | 30            |
| 2     | Centre of the first panel | 1590                                                     | 740           | 73           |
| 3     | Middle post               | 767                                                      | 740           | 3.6          |
| 4     | Centre of the second panel| 1410                                                     | 740           | 62           |
| 5     | Right end post            | 907                                                      | 740           | 20           |

Figure 7. Plan and side views for the maximum deformation of 997 mm for impact load in Case 1.

Figure 8. Plan and side views for the maximum deformation of 1590 mm for impact load in Case 2.
5. Conclusion
The comparative study between numerical simulation and full-scale field testing of steel parapet railing under impact of heavy truck loads presented herein is to highlight the ability of numerical simulation in estimating the performance of such structures and to tackles the shortcoming of field testing. The chosen 3S two-beam steel parapet design was modelled and simulated using the SolidWorks software and the NASTRAN/PATRAN software, respectively. Total of five case study was derived to ensure the reliability and accuracy of the obtained results. It is found that, Case 3 recorded the lowest difference percentage of 3.6% for the maximum deformation of the simulation and field testing results. However, other case studies recorded more than 10% discrepancy of the maximum deformation (i.e. Case 1, 2, 4 and 5).

Therefore, it can be assumed that, during the actual field testing, the impact heavy truck load was applied at a similar location as in Case 3 (i.e. middle post). As conclusion, the numerical simulation provides a viable approach in estimating the performance (i.e. quality) of bridge parapet railing with minimum operational cost and less time required. Besides, based on this study, the numerical simulation also predicted the performance of the parapet railing when the impact load applied at a different location along with the parapet panels. These results are important to ensure overall stability and integrity of the bridge parapet and to avoid the possibility of structural failure. Consequently, the numerical approach is suggested as the best approach to tackle the shortcomings of the field testing.
References

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