Explicit finite element modelling of bridge girder bearing pedestals

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EXPLICIT FINITE ELEMENT MODELLING OF BRIDGE GIRDER BEARING PEDESTALS

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ABSTRACT

Bridge girder bearings rest on pedestals to transfer the loading safely to the pier headstock. In spite of the existence of industry guidelines, due to construction complexities, such guidelines are often overlooked. Further, there is paucity of research on the performance of pedestals, although their failure could cause exorbitant maintenance costs. Although reinforced concrete pedestals are recommended in the industry design guidelines, unreinforced concrete and/or epoxy glue pedestals are provided due to construction issues; such pedestals fail within a very short period of service. With a view to understanding the response of pedestals subject to monotonic loading, a three-dimensional nonlinear explicit finite element micro-model of unreinforced and reinforced concrete pedestals has been developed. Contact and material nonlinearity have been accounted for in the model. It is shown that the unreinforced concrete pedestals suffer from localised edge stress singularities, the failure of which was comparable to those in the field. The reinforced concrete pedestals, on the other hand, distribute the loading without edge stress singularity, again conforming to the field experience.

KEYWORDS

Explicit finite element modelling, concrete bridge pedestal, concrete damage plasticity, localised damages, stress singularities, surface to surface contact.

INTRODUCTION

Bridge girder bearings rest on pedestals to transfer the loading safely to the pier headstock. The pedestals are not normally structurally designed and hence their performance is, hitherto, an unknown. Bridge pedestals are sources of high stress zones and pose significant challenges to keep them serviceable over their intended design life. Pedestal failure can cause significant serviceability problems which could culminate into closure of bridge to traffic. Poor understanding of their behaviour do not allow for preventive/planned maintenance – under emergency condition, exorbitant costs are incurred. A maintenance free pedestal would be ideal; however, such improved life pedestals can only be developed through improving the understanding of their performance to loading and maintenance regime and functioning of their adjoining components.

The performance of bridge pedestal is highlighted as part of and/or over-shadowed by the bridge bearing responses (Pritchard 2012; Rossow 2006). Only a limited research has been conducted on bridge pedestal (Hite et al. 2008) and some studies are indirectly related to this problem such as the concrete pedestal of the column-foundation joint. There are some studies related to pedestals but are focused on the bearing capacity for concrete (Ince and Arici 2004; Bonetti 2005; Roberts-Wollman et
al. 2006; Escobar-Sandoval et al. 2006) and internally or externally reinforced concrete (Ahmed et al. 1998). Most studies were conducted based on the experimental works which are related to the confinement effects of the enveloping concretes. The previous researchers (Shelson 1957; Hawkins 1968; Niyogi 1974) relate the bearing capacity of concrete to its compressive strength and the bearing area to loaded area ratio. It can be noted that the effects of confinement of the internal or the external reinforcements are not considered in these strength prediction formulae. Additionally, there is only a limited fundamental explanation on the load transfer mechanism that initiates the failure of concrete pedestal associated with the bearing capacity of the concrete. With the advanced engineering software available, more complicated model can be analysed and the behaviour of structure can be further explained in more detail. Therefore, in this research the failure mechanisms of the concrete bridge pedestal are predicted through finite element modelling.

**FINITE ELEMENT MODELLING**

By taking advantage of the symmetry, a quarter of the concrete pedestal and the steel bearing plate are modelled as a three-dimensional (3D) framework in ABAQUS explicit (see Figure 1). The concrete pedestal is fixed at bottom and symmetric at both sides. The concrete pedestal and steel plate were modelled using an 8-node linear brick, reduced integration and hourglass control 3-D stress element (C3D8R). The interface between the steel plate and the concrete pedestal was modelled using surface to surface contact. The contact interaction properties were based on the “hard contact” pressure-over closure and the penalty friction coefficient of 0.3. The steel reinforcement was modelled using a 2-node linear 3-D truss element (T3D2). The diameter of steel reinforcement used was 12mm diameter bar. The reinforcement was embedded into the concrete using embedded region constraint where the concrete acted as a host element for the steel reinforcement as shown in Figure 2.

Finer mesh was considered at the edges (see Figure 2). As the purpose of the study reported in this paper is limited in scope as to compare the unreinforced and reinforced concretes, a simple approach of application of uniform pressure load on the steel bearing plate was used; for this purpose, the pressure was set as 100MPa. This pressure load should keep the steel elastic; however, unconfined concrete should have failed. The intention was therefore to study the modes of failure/ states of stress in the pedestal.

The concrete was represented using a damage plasticity model. The Young’s modulus for steel and concrete was 200GPa and 26.48GPa respectively. The Poisson’s ratio for the steel and concrete was 0.3 and 0.167 respectively. The behavior of concrete (in compression and tensile) can be found in Appendix (refer Figure 11).
RESULTS AND DISCUSSIONS

Comparisons have been made between unreinforced and reinforced concrete pedestals in terms of stress distribution, deflection level and deformation shape. Due to page limitations, only a selected key output are presented; point A, B and C as shown in Figure 3. (Points A and B separated by 14mm)

Vertical Stress Distributions

Under the 100MPa applied loading, the stress at Point A was 155MPa (unreinforced) and 150MPa (reinforced); however, at Point B, the stress was 80MPa (unreinforced) and 90MPa (reinforced) are shown in Figure 4(a). This shows both types have exhibited similar levels of stresses; however, the strain levels in reinforced pedestal are lower than that of the unreinforced pedestal at both points. The percentage difference is about 33% at Point A and 28% at Point B, which is significant. It should be seen that under the 100MPa applied stress, both points have shown non-linear stress-strain characteristics. To illustrate the stress level on average is still elastic, Point C at the centre-top of the pedestal was considered. The stress-strain response of Point C is shown in Figure 4(b); the linearity shows the material is elastic due to confinement in spite of the strength of concrete was only 33MPa.

![Figure 3. Vertical stress contour of concrete pedestal](image)

![Figure 4(a). Stress level at Point A and B](image)

![Figure 4(b). Stress level at Point C](image)
**Vertical Deflection and Deformation Shape**

The vertical deflection has been compared between unreinforced and reinforced concrete pedestal. Figure 5 shows the deflection at two selected points (one in compression zone and the other in tension zone – identified as point A and B respectively as shown in Figure 6(a) and 6(b). The deflection contour for unreinforced pedestal is localised especially at the edge contact of steel plate corner (see Figure 6a). However, Figure 6(b) shows that the deflection contour for reinforced pedestal is uniformly distributed throughout the contact surface. This phenomenon explains that the stress singularity in unreinforced concrete pedestal was greater than that in the reinforced concrete pedestal. Further, the maximum deflection of the unreinforced concrete pedestal was greater than the reinforced concrete pedestal in both tension (15.79%) and compression (63.76%) zones. This stress singularity has been confirmed with field experience especially in the issue of cracking and spalling of bridge pedestal that lead to reduction of bearing area under the bottom bearing plate as illustrated in Figure 7.

**Effects of Steel Reinforcement**

The effects of steel reinforcement were investigated by measuring the axial stress of steel reinforcement. Figure 9(a) and 9(b) show the axial stresses at two selected points (one in tension zone and the other in compression zone – identified as point P and point Q respectively as shown in Figure 8. The numerical results showed that the axial stress of steel reinforcement can reach up to 254MPa (in tension). It showed that the steel reinforcement was not yield (500MPa) that explained the uniform
deformation level in Figure 6(b). Thus, the concentrated stress in the concrete also reduced. This reinforcement also enables to provide additional load carrying capacity when the loaded steel bearing plate penetrating the concrete surface. Meanwhile, the axial stress of reinforcement in compression showed was reached up to 34.6MPa (in compression). It showed that the reinforcement was able to provide some additional resistance for concrete especially to minimize the bulging effects in concrete pedestal.

![Steel plate](image1.png)  
**Concrete pedestal**  
![Point P](image2.png)  
![Point Q](image3.png)

**Figure 8. Steel reinforcement in tension and compression**

**Interface Contact Pressure**

The contact pressure has been determined from this model (see Figure 10a). The numerical results showed that the nonlinear contact pressure was maximum which localised at the unsupported edge. This localised issue has been confirmed with field experience especially in the issue of damaged mortar pad as illustrated in Figure 10(b).

![Contact pressure](image4.png)

**Figure 10(a). Contact pressure of unreinforced and reinforced concrete pedestal**

![Loss of contact due poor mortar pad](image5.png)

**Figure 10(b). Loss of contact due poor mortar pad**

**Figure 9(a). Axial stress-strain curve for steel reinforcement (in tension)**

**Figure 9(b). Axial stress-strain curve for steel reinforcement (in compression)**

![Axial stress-strain curve](image6.png)
CONCLUSIONS

This paper has presented the beneficial effects of reinforcement to the structural performance of concrete pedestals. Through the numerical results presented in this paper, it can be concluded that the reinforcement in the concrete pedestal is crucial as it can change the deformation from localised zones to uniform deformation. The effects of bulging in concrete pedestal leading to spalling of concrete can be optimised by provided reinforcement in the concrete pedestal. The reinforcement is also found to reduce the stress levels in the concretes – which could translate into reduction in damage and hence increase in life of pedestals.

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REFERENCES


APPENDIX

Figure 11. Compressive and tensile behaviour of concrete