

Crack Propagation of Prestressed Concrete Multi Girder Bridge Subjected to Vertical Symmetric Loads

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Abstract. The prestressed concrete multi girder bridge is composed of main beams and diaphragms. Cracks are inevitably existing in the structure. The regularities of crack propagation of the prestressed concrete multi girder bridge subjected to vertical symmetric loads are studied based on nonlinear finite element theories. From shell element degraded from continuous body, steel and concrete are modeled by layered shell element. With some available criteria, the material nonlinear properties of concrete and steel are considered. Then the procession of cracking, yielding and failure of prestressed concrete multi girder bridge is imitated and the analytical three-dimensional procedure is compiled. For a certain prestressed concrete multi girder bridge when subjected to two typical vertical symmetric loads, the computational results show that the cracks emerging in the diaphragms are earlier than those in the main beams. The crack propagation pictures of important load rands are listed in order to prove the significant regularity. For practical engineerings, emphases should be also put on the cracks in the diaphragms.

Introduction

The prestressed concrete multi girder bridges are widely used in the modern highways and urban roads[1-3]. The prestressed concrete multi girder bridges can be mainly divided into box girder bridge, T-shaped girder bridge, jointed hollow plate bridge. The computational theories for this kind of bridge, mainly including beam-grid method, plate-grid method and orthogonal plate method, have been gradually coming into maturity. However, all these methods have the same deficiency that they are correct only for the elastic stage, which means all the main beams and diaphragms are uncracked. For the practical bridges, it is inevitable that they are working with cracks due to the reasons such as the low design grade or overweight vehicle. Thus, when the cracks exist in the bridges, it may lead to deviation from the fact if the traditional design concepts are utilized. As is known to all, the cracks in the main beams always attract much attention because the main beams are the important components which are burdened with the added loads. With the development of the analytical theory for the multi girder bridge, much attention has been paid to the diaphragms because diaphragms in the upper structures of the multi-beam bridges are the important transversal connections. When the cracks emerge in the main beams or diaphragms, this problem belongs to nonlinear mechanics. And the available FEM softwares can not settle the problem efficiently.

With the corresponding nonlinear element theory for reinforced concrete structure, the problem of the regularity of crack propagation of prestressed concrete multi girder bridge subjected to different kinds of vertical symmetric loads are studied in detail.

Smearred crack model

One of the most important characterizations of concrete is lowness of tensile strength, which leads to that the concrete structure works with cracks in many circumstances. Cracks engender the changing of stress and decreasing of stiffness, which is the basic nonlinear factor in concrete. Correct modeling of cracks, which is difficult to complete, is the key problem in the reinforced concrete structure

analysis. At present, the crack models can be mainly divided into three kinds: discrete concrete model, smeared crack model and fracture mechanics model. Fracture mechanics model is still in the range of theoretic research because of the complexity of fracture mechanism and it is difficult to be applied in practical bridges. Discrete crack model takes the cracks as the boundary of the elements and when the new cracks emerge, it is necessary to partition the elements again, which is much more complicated and costs much computational time and obstructed the application of this crack model. As for a practical concrete structure with a large number of cracks, it is impossible to utilize the regeneration of elements to trace the crack. In smeared crack model, when the principle tensile stress or strain of the point of the concrete element exceeds the limit tensile stress or strain, it is supposed that the periphery regions near the point are cracked and parallel minute cracks appear around the point in the element. The crack direction is perpendicular to the principle tensile stress and the cracks have no effect on the continuity of the concrete material. Conformed to the continuous medium mechanism, the cracked can be considered as orthogonal material.

In smeared crack model, only the material constitutive matrix should be revised and there is no need to change the element type or regenerate the element meshing, which is easily finished in nonlinear procedure and can satisfy the engineering calculative precision. Thus, smeared crack model is adopted to simulate the tensile nonlinearity of concrete.

Madrid hardening criterion

The hardening criterion determines the post yielding surface in the plastic deformation and defines the relationship between the yielding surface and the accumulative plastic strain. Combined with the physical definitions of efficient stress and efficient plastic strain, the mechanical performances of the concrete can be depicted by using the result of single axis test to deduce that of the multi-axis test. And the hardening parameter H' in elastic-plastic matrix can be worked out by computing the slope of the efficient stress to efficient plastic strain. The relationship between the efficient stress σ and the efficient plastic strain ε_p in Madrid hardening criterion is

$$\sigma = E_0(\varepsilon_e + \varepsilon_p) - \frac{1}{2} \frac{E_0}{\varepsilon_0} (\varepsilon_e + \varepsilon_p)^2 \quad (1)$$

Where E_0 is the initial elastic modulus and ε_0 is the total strain corresponding to the single axis compressive strength f_c , which equals $2f_c/E_0$. ε_e is the elastic strain, which equals σ/E_0 . The equation depicting the relationship between the efficient stress σ and the efficient plastic strain ε_p can be derived as

$$\sigma = -E_0\varepsilon_p + \sqrt{2E_0^2\varepsilon_0\varepsilon_p} \quad (0.3f_c < \sigma \leq f_c) \quad (2)$$

Where the hardening parameter H' can be determined from (1) and (3). f_t is the concrete tensile strength of single axis and ε_u is the concrete limit compressive strain and α, ε_m are the concrete tension stiffening parameters. The flowing, yielding and crushing criteria are respectively modeled by related flowing rule and Owen yielding and crushing criteria. The displacement convergence criterion is utilized and the convergence tolerance is 2.5%.

Study on load transversal distribution

In order to grasp the ultimate loads of the prestressed concrete bridge, the whole course test was carried out. The design loads of the south part of the bridge are super-20 grade of vehicle and 120 grade of trailer. The width of half part is 13m and the traffic lane width of half part is 10.75m. The bridge is composed of 6 pieces of single T-shaped beams and 5 pieces of diaphragms. G1 denotes the center line of the first T-shaped beam and the rest beams are numbered by turn. The length of the T-shaped beam is 20m and the width of the flange plate is 1.6m and the height of the beam is 1.4m and the width of the web plate is 0.18m and the width of the hoof is 0.40m. The materials of the bridges

include No. 50 concrete and 1860MPa high strength steel wire. The pores are formed by the metal bellow and the prestressed steels are $24\phi^s5$, whose controlling stress is 1200MPa. The anchorage system is Fluoride's anchor. The bearings are comprised of plate rubber and the bridge foundation is bored pole. The detailed configurations of common steels and prestressed rebars can be consulted in [9]. The prestressed concrete bridge is a typical thin walled engineering structure, which is modeled by finite elements. Combined with the test data in [9], the nonlinear procedure is compiled and the whole course analysis is completed, which suggests the reliability of the procedure. Two typical kinds of symmetric loadcases are studied. The spot where the loads are added is the point of intersection of the main beam and the top plate. The quantity of adding loads per load grade at one spot is 5 ton.

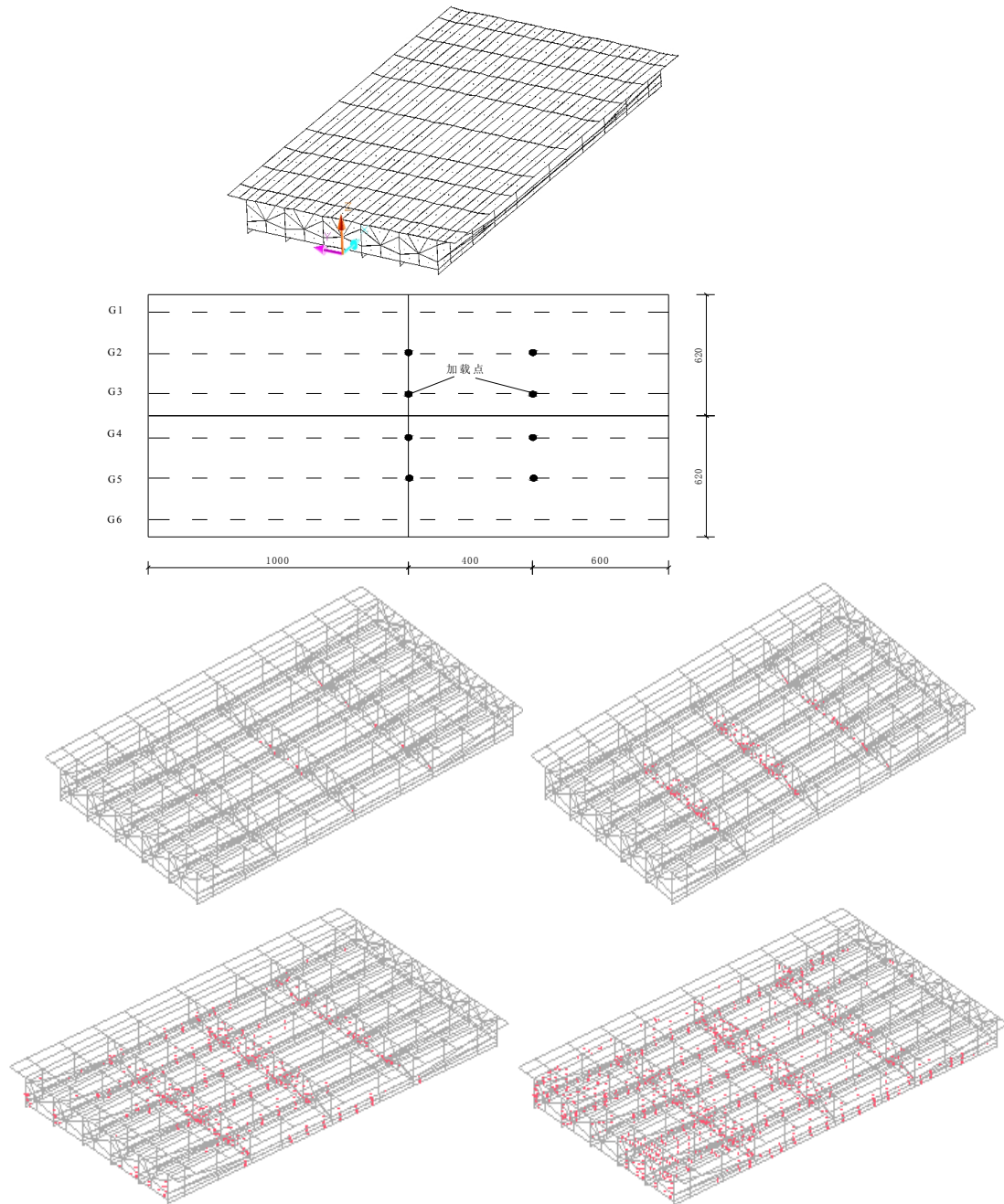


Fig.1 Load adding position of the section

Summary

(1) Through analysis of designed typical loadcases, the transversal connection capabilities and all main beams cooperating in harmony are weakened when the cracks emerge in the diaphragm, which makes the load transversal distributions changed adversely.

(2) The load transversal distribution coefficient obtained from nonlinear procedure is coincident with that from the rigid plate theory when the bridge is subjected to uniform loadcase. When subjected to symmetric or offset loadcase, the results from these two methods are not the same. When the cracks emerge in the diaphragms, greater error will be engendered and the computational results are more unsafe if the traditional rigid theory is still utilized.

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