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Numerical Simulation for Local Stability of Box-section Columns*

F. Yue

Dept. of Civil Engineering, Shanghai Jiaotong University, China.
E-mail: f.yue@sjtu.edu.cn

ABSTRACT
A numerical simulation in the paper is carried out based on a scaled model test which has already been conducted for the purpose of getting the structural behaviors of mechanisms, modes, actual safety factor of local stability and ultimate capacities of the stiffened steel plates in box-section columns for structural design of Shanghai Lupu Bridge. An updated advanced nonlinear finite element analysis is conducted on the specimen models using ANSYS in order to study the capacity and failure modes of the tested specimens. The numerical simulations are verified by comparisons with the results of the test. This paper provides a useful and economical way for the safe design on local stability of the stiffened steel plates in box-section columns.

KEYWORDS: *steel structures, stiffened steel plates, box section columns, local stability, numerical simulation*

1. GENERAL INSTRUCTIONS

Thin-walled steel box-sectioned beams and columns are widely used in building or bridge structures in civil engineering. These members are normally fabricated by thin-walled plates stiffened with open or close ribs. The structural characteristics of these piers make them susceptible to damage in the form of local as well as overall interaction buckling when subjected to static, cyclic or earthquake loading.

Grondin et al. [1] has studied the stability of plates stiffened with tee-shape stiffeners using a finite element model. Four series of stiffened plate panels were modeled using a finite strain fournode shell element. The parameters investigated are: the shape and magnitude of initial imperfections in the plate; residual stress magnitude and direction of applied uniform bending; plate slenderness ratio; plate aspect ratio; and plate to stiffener cross-sectional area ratio. The effect of the investigated parameters on the axial load carrying capacity and the mode of failure of stiffened plates is investigated both in the elastic and inelastic ranges. A comparison of these results with design guidelines indicates that the guidelines are generally conservative for cases where initial imperfection magnitudes do not exceed the guidelines' prescribed maximum.

Shin et al. [2] presents a set of new strength equations for box girder flanges stiffened with open ribs subjected to uniaxial compression. A total of eighty four hypothetical compression flange panels were modeled with wide ranges of slenderness parameters and then were investigated by nonlinear finite element analysis (FEA). Both conventional and high performance steels (HPS) were investigated in the analysis models by utilizing multi-linear constitutive relationships. Initial imperfections and residual stresses were also considered in the analysis. New design equations to predict the in-plane compressive strengths of the stiffened flanges are proposed based on the FEA results and compared with other design equations specified in Eurocode 3, the Federal Highway Administration (FHWA) design specifications, and the Japanese Road Association (JRA) specifications, and equations previously proposed by other researchers. It has been found that the equations provided in the above design codes underestimate the strengths determined from the HPS models, which may result in an inefficiently conservative strength design. Shin et al. [3] also studied box girder flanges stiffened with U-shaped ribs in similar ways mentioned above.

Ismail et al. [4] aimed to carry out extensive numerical investigations about the effect of various structural parameters on the dynamic performance of stiffened box steel bridge pier under a strong earthquake ground motion. The considered structural parameters are the local slenderness ratios of stiffener and stiffened wall as well as the global slenderness ratio of the pier. In the present study, all investigated piers are made of high tensile steel with high yield ratio. The non-linear time history analyses are carried out using in-house Finite Element Program. It is found from the study that the increase in slenderness ratios of stiffener does not only increase the

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damage index, but also may lead to the full collapse. Furthermore, the damage index increases with the increase of local slenderness ratio of stiffened wall and the global slenderness ratio. Also, it is found that when the local buckling is not the dominant eigen mode and the pier behave as a single degree of freedom, the natural period has destructive effects when it is close to predominant period of the earthquake.

Yoo et al. [5] presented an optimum design of longitudinal stiffeners for box-girder compression flanges. This study presents results that are based on 3D finite-element analysis of several hundred hypothetical compression flange models stiffened by varying numbers of longitudinal stiffeners with realistic dimensions. Analytical data were reduced using nonlinear regression analysis to a simplified design equation suitable for practicing engineers.

However, there have been almost no much guidelines or relative specifications and relatively few reports or papers in China for the safe design of local stability for stiffened plates in columns[6][7]. In this paper, an updated numerical simulation is carried out based on a scaled model test which has already been conducted for the purpose of getting the structural behaviors of mechanisms, modes, actual safety factor of local stability and ultimate capacities of the stiffened steel plates in box-section columns for structural design of Shanghai Lupu Bridge. Advanced nonlinear finite element analysis is conducted on the specimen models using ANSYS in order to study the capacity and failure modes of the test specimen.

2. SCALE MODEL TEST ON THE LOCAL STABILITY OF A STEEL BOX-SECTION COLUMN

Shanghai Lupu Bridge, a half-through composite-system steel arch bridge with its 550-metre-long main arch, 100m of the radius vector, 1/5.5 of rise span ratio, completed in 2003, is another large highway bridge across Huangpu River besides Shanghai Nanpu, Yangpu and Xupu Bridge in Shanghai, China. The 3,900-metre-long bridge breaks the record for this type of bridge with its 550-metre-long main arch, 32 meters longer than that of the New Virginia Bridge in the United States. The superstructure has six main parts such as arch rib, wind brace, main beam, hanger rod, standard and tie rod. The main beam and the standard are all orthotropic structure[9].

Besides calculation of load-carrying capacity and global stability calculation, analysis of local stability is an essential work to carry out on the main arch columns, which mainly support uniaxial compression force. Therefore, in order to get the mechanism, mode and the actual safety factor of local stability, scale model test is indispensable for design of this kinds of box-sectioned columns with stiffened plates.

2.1. Scale Test Model

According to structural design of the bridge and the practical condition of the lab, a 1:4 scale test model is decided with the same materials as actual bridge, and with length of 6500mm, height of 2250mm and width of 1275 (Figure.1, 2) [8][9].

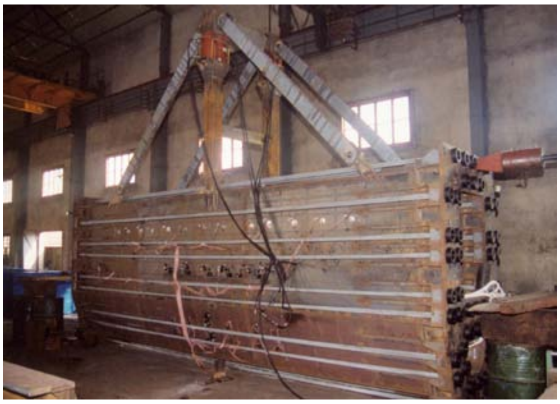

Figure 1 The scale test model

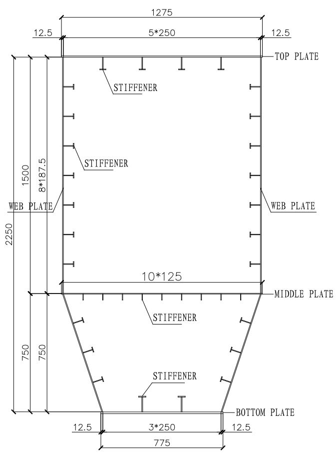

Figure 2 The section drawing of the scale test mode (Unit: mm)

2.2. Loading Procedure

Based on theoretical pre-analysis, the maximum loading may reach 23000kN in this test. Therefore, a strong counteracting rack and a complex load distributing equipment are needed. In the test, a self-counteracting loading system for easy operation is adopted to satisfy the loading requirement.

The end plates, welded at the two ends of the segment, many holes are drilled for going through enough wire strands. There are totally 50 bundles of wire strands used for self-counteracting loading, each of which is composed by 37 roots of high tensile steel wire. The test loading includes several stages such as 200Mpa, 250 Mpa, 300 Mpa and 345 Mpa, respectively, and in each of the stages, the pressure value of the section of the test coupon was measured and recorded[8][9].

2.3. Result of the Test

As the loading reachs 20380-20674kN, while at the same time the corresponding pressure of the section is 310~314Mpa, the web plate firstly present local bucking, then, come the top plate and middle plate as the section pressure increases to 322Mpa. The shape of the local bucking looks like waviness with concave-convex deformation. At last, the loading is over while it is up to 326Mpa, less than 345 Mpa of the characteristic value of strength of the steel test coupon.

3. NUMERICAL SIMULATION FOR LOCAL STABILITY OF BOX-SECTION COLUMNS

The column was modeled and analyzed using the commercial software ANSYS. The sizes and mechanical properties of the simulation model are all same as the test model. The size All of the members in the column include webs, flanges, T-shaped stiffen open plates, transverse stiffeners and transverse diaphragms are modeled by element SHELL43. The reason of choosing SHELL43 is that it may allow for large deformation and large strain. The mesh size was found to yield satisfactory convergence. The SHELL43 element is a four node shell element that allows for changes in the thickness as well as finite membrane strains. The model invoked large displacement using a Total Lagrangian formulation. The plate material behavior was modeled by an elastic-plastic constitutive model.

The parameters investigated in the simulations are the effects of the magnitude and shape of initial imperfections, residual stresses, plate slenderness, plate aspect ratio, and stiffener to plate area ratio. The numerical simulations are verified by comparisons with the results of the test.

Figure 3 Local bucking mode in the test

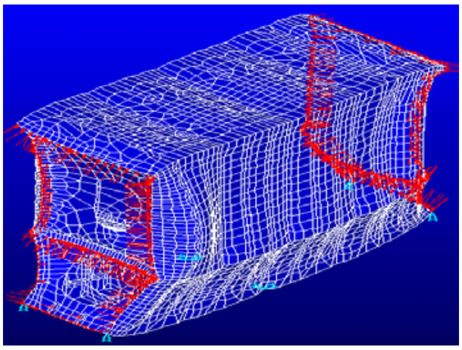

Figure 4 Local bucking mode in the simulation

In the simulation the local bucking also firstly occurs at the web plate when the loading reaches about 21600kN, marginally higher than that in the test. Figure 4 is the local bucking mode in the simulation. The shape of the local bucking also looks like waviness with concave-convex deformation which is similar as the practical bucking mode taken place in the test shown in Figure 3.

4. CONCLUSIONS

In the paper a numerical simulation is carried out based on a scaled model test. The results from the simulation agree well with those of the test, therefore, this paper may provide a useful and economical way for the safe design on local stability of the stiffened steel plates of box-section columns.

The load-carrying capacity of the steel box-section column with uniaxial compression is mainly decided by local bucking. The influence of initial imperfection such as weld defects, initial eccentricity, manufacturing error, are essential to the load-carrying capacity. The local bucking modes of the main components show that enough rigidity of the transverse diaphragm, transverse stiffeners and the longitudinal stiffeners of the plates can efficiently increase the local stability of neighboring plates for which they stiffen. However, a series of further parametric analysis are still needed to carry out in future to investigate the effect of various geometric characters on local stability.

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