Proceedings of the HTR 2014
Weihai, China, October 27-31, 2014
Paper HTR2014-71379

Nonlinear finite element analysis of a test on the mechanical mechanism of the half-steel-concrete composite beam in HTR-PM

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Abstract –According to a large-span half-steel-concrete (HSC) composited beam in the composited roof in the HTR-PM, a 1:3 scale specimen is investigated by the static load test. By analyzing the loading, deflection, strain and fracture development of the specimen in the process, studying the mechanical characteristics and failure pattern of such components. The ANSYS finite element software is utilized in this paper to analyze the nonlinearity behavior of the HSC beam specimen, and through comparing the experimental results and the numerical simulation, it can be illustrated that the finite element model can simulate the HSC beam accurately. From the test results, it can be concluded that by means of appropriate shear connection and anchorage length, steel plate and concrete can work together very wel1 and the HSC beam has good load carrying capacity and ductility. These conclusions can serve as a preliminary design reference for the large span half-steel-concrete composite beam in NPP.

I. INTRODUCTION

Steel-plate reinforced concrete (SC) structure is a new structure with high strength, good seismic performance, easy construction, which was applied in many fields such as nuclear power plants, mines, oil storage, city roads and bridges[1-2]. Nie Jianguo did experimental study of the Steel Plate-Concrete Composite (SPCC) beams, and the bearing capacity was theoretically analyzed[3]. ShanDong Shidao Bay high temperature gas cooled reactor nuclear power plant (HTR-PM) demonstration project will use a large-span half-steel-plate reinforced concrete (HSC) composited roof system. However, the development of this system is still at the early stage[4-7]. So only a few comprehensive researches have been done on such a type of structure in the resistance mechanism and the failure mode, and there is no related design specification in China. Therefore, it is necessary to study it systematically and in-depth.

Current research for composite beam’s design method mainly through three ways: practical engineering, experimental study and numerical simulation analysis[8-10]. Experimental study subject to the conditions of test equipment, so finite element program is used to HSC composite beam calculation model and carries on the numerical simulation analysis as an important supplement of the experimental study is particularly important. The ANSYS finite element software is utilized in this paper to analyze the nonlinearity behavior of the HSC beam specimen, and through comparing the experimental results and the numerical simulation, it can be illustrated that the finite element model can simulate the HSC beam accurately. From the test results, it can be concluded that by means of appropriate shear connection and anchorage length, steel plate and concrete can work together very wel1 and the HSC beam has good load carrying capacity and ductility. These conclusions can serve as a preliminary design reference for the large span half-steel-concrete composite beam in NPP.

II. FINITE ELEMENT ANALYSIS

II.A. Project background

ShanDong Shidao Bay high temperature gas cooled reactor nuclear power plant (HTR-PM) demonstration project will use a large-span half-steel-plate reinforced concrete (HSC) composited roof system. The welded steel-plate is used as the lower flange of the roof system, on which the vertical steel plates and the studs are welded as the web stiffeners and the shear connectors respectively. The bottom steel-plate and web are composed with the cast-in-situ concrete in which the reinforcing steel bars are arranged to enhance the bearing capacity and integrity. The top flange of the roof system is composed of the reinforced concrete (Fig.1).

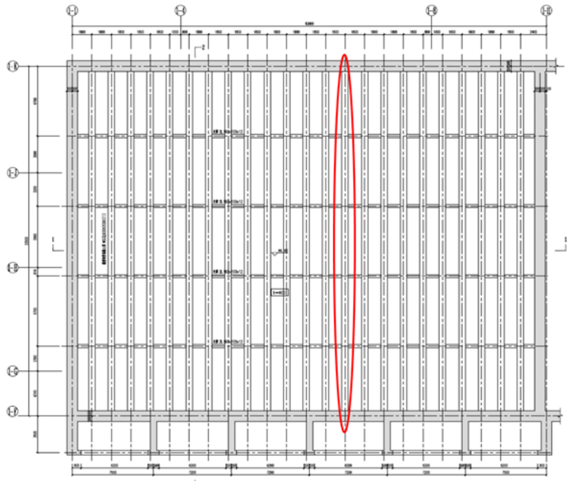


Fig.1 Layout of the roof structure.

Experimental study subject to the conditions of test equipment, make full scale test is hard to do, even if the scale experimental study its not the big amount. According to the single HSC beam in the the composited roof, a 1:3 scale specimen is investigated by the static load test, the section is shown in Fig.2.

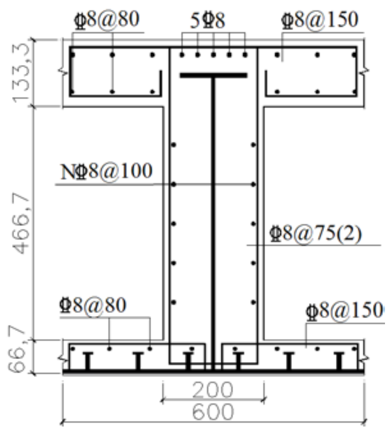


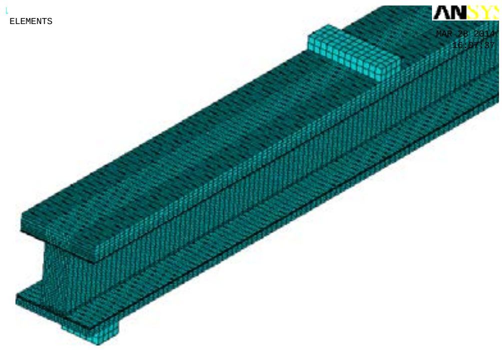
Fig.2 Section size of half-steel-concrete composite beam (Unit:mm).

The actual construction process is not considered due to the larger specimen size and the limitation of the test facility. Firstly, a molding method is used to manufacture the specimen beam outside. And then, the specimen is lifted to the test ground. By analyzing the loading, deflection, strain and fracture development of the specimen in the process, studying the mechanical characteristics and failure pattern of such components, the Loading scheme and test instrumentation is shown in Fig.3.

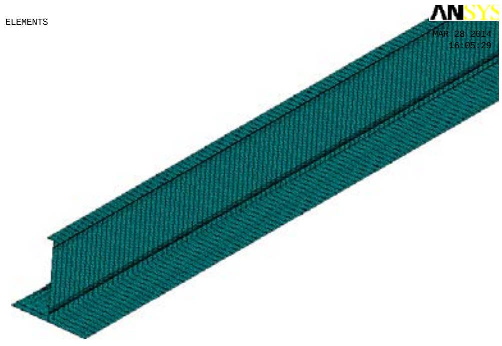
Fig.3 Loading scheme and test instrumentation.

II.B. Numerical analysis

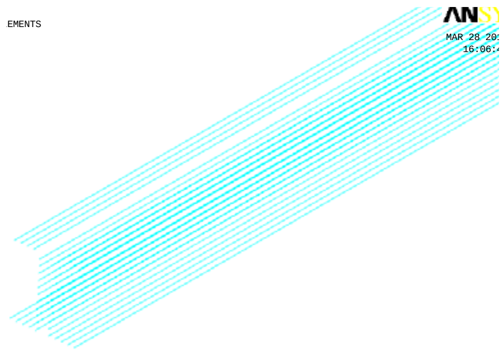
The numerical model of the HSC beam specimen is built up and the mechanical properties of the one-time forming specimen and the multi-step forming specimen are compared via the numerical model. The model consists of the bottom steel-plate , web and the filled concrete. The dimension of the composite beam is 12000mm（L）×667mm（H）×600mm（W）. The concrete is simulated by the element solid65, which is used to model concrete structures. Link8 is used to model with steel bars, and the steel plate is simulated by the element of shell181. It can achieve satisfactory results by using APDL under mechanical coupling environment between solid element and link element[11], the finite element model is shown in Fig.4.



Concrete structures



Steel plate



Steel bars

Fig.4 Model of the HSC composite beam by using ANSYS.

The elastic behavior of the concrete and the tendons were defined by their modulus of elasticity and poisson ratio, concrete exhibits both elastic and inelastic behavior during loading, the inelastic behavior is complex because it involves modeling of the cracking behavior, compression hardening, and tension softening of the concrete according to the constitutive model of the concrete in GB 50010-20021, as shown in Fig.5[12]. The "concrete damaged plasticity model" available in the software package was used. The steel constitutive model uses the ideal elasto-plastic model, The yield strength of plate is 335MPa.

In order to study the resistance properties of the large-span half-steel-plate reinforced concrete (HSC) composite beam, the structure is simplified with the following assumptions: 1) In this model, it was assumed that concrete, steel bars and steel plate kept contact with each other throughout the loading process, and the shear connectors were represented by interfaces with distributive cohesive force. 2) For displacement boundary condition of the HSC composite beam, the end point of simple beam is assumed as hinge joint while the other portions are set free, and the block rigidities are infinitely great.

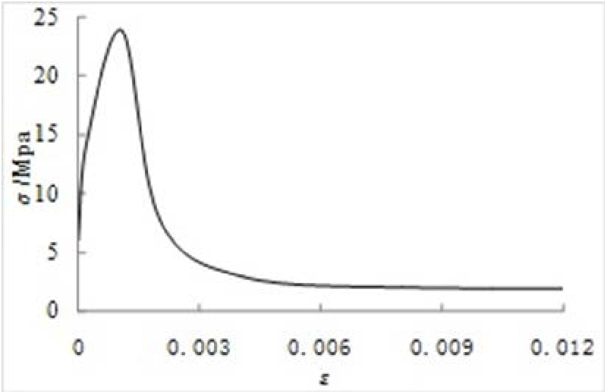


Fig.5 Relationship between compressive stress-inelastic strain of concrete.

III RESULT AND DISCUSSION

The displacements of steel-plate, concrete, steel bar and mid-span deflection of the HSC composite beam were calculated and compared with the experimental results. The conclusions of numerical analysis agree well with the in-site measured data is shown in Fig.6, the vertical displacements of HSC composite beam under ultimate forces is shown in Fig.7.

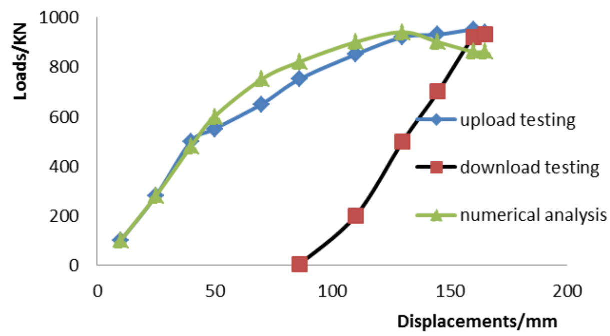


Fig.6 Comparison of analytical results of displacements and experimental results.

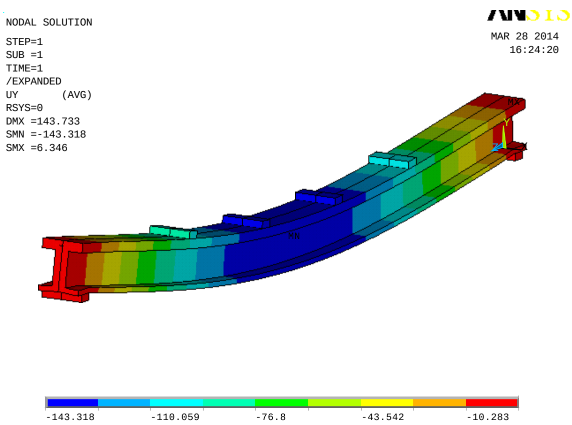


Fig.7 Vertical displacements of HSC composite beam under ultimate forces.

From Figs.6-7, we can learn that: 1) Bending stiffness has considerable impact on mid-span deflection and end slip when it is comparatively small; the mid-span def1ection and end slip decrease significantly with the increase of bending stiffness. However, when the slip stiffness reaches a certain quantity, its impact on mid-span deflection and end slip decreases to be negligible. 2) The bending deformation has certain inf1uence on mid-span vertical displacement, and the larger the load is, the greater the influence is. 3) The impact of shear deformation on end slip can be neglected. 4) With the increase of bending stiffness, the strain of bottom steel-plate of HSC composite beam decreases, while shear lag effect becomes more significant.

The bearing capacity of the HSC composite beam is provided by external steel plates and the reinforced concrete. According to the results of the finite element analysis，the maximum bearing force of HSC composite beam can reach 900kN, while the in-site measured data is 950kN.

It shows that the errors between the results computed by the finite element method and the test from Fig.6, which can be controlled in the range of 5％to 10％. The main factors causing errors are as follows：1)The crashed concrete is not considered in the finite element analysis in order to guarantee the calculation convergence of the model；2) For displacement boundary condition of the HSC composite beam, one end point of simple beam is assumed as hinge joint and the other end is constrainted in vertical direction, in fact the horizontal friction during real loading process should be considered. On the whole, the test results are reasonable and can meet the real force state of the structure compared with the results of the finite element method.

IV CONCLUSIONS

The following conclusions are drawn from the investigations conducted on the prestressed concrete containment simulating by using ANSYS program.

(1) By analyzing the loading, deflection, strain and fracture development of the specimen in the simulating process, studying the mechanical characteristics and failure pattern of such components. It can be concluded that by means of appropriate shear connection and anchorage length, steel plate and concrete can work together very wel1 and the HSC beam has good load carrying capacity and ductility.

(2) It shows that there errors between the results computed by the finite element method and the test results, which can be controlled in the range of 5％to 10％. On the whole, the conclusions of numerical analysis agree well with the in-site measured data and can meet the real force state of the structure in practical.

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ACKNOWLEDGEMENT

The study is supported by the National science and technology major projects: large-scale advanced pressurized water reactor nuclear power plant CAP1400 safety evaluation & review technique and verification independently (Grantno. 2011ZX06002-10-16).