ISSN: 1813-4890

Finite element analysis of fiber reinforced concrete box beam

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Abstract

There are large differences between the formulas related to shear bearing capacity in national codes, so more in-depth understanding and research are needed for the shear damage mechanism of reinforced concrete members. In the actual construction process, there are difficulties in accurately laying out shear reinforcement in box girders, especially in narrow cross-sections and where intensive reinforcement is required, so it is important to reduce the amount of shear reinforcement used by selecting appropriate methods.The effect of fiber type and fiber admixture on the shear performance of the fiber concrete box beam is investigated through the established 20 box beam model. The ultimate load capacity of the box beam increases with the fiber incorporation, and the ultimate load increases with the increase of fiber incorporation. The fiber incorporation can reduce the amount of hoop reinforcement used in the members to some extent. It can make the member change from brittle shear damage to ductile bending damage.

Keywords

Fiber reinforced concrete, Box beam, Finite element, Fiber.

1. Introduction

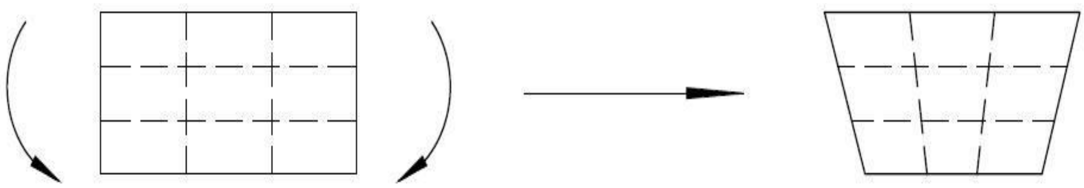
Many bridges with reinforced concrete structures in actual construction use box girders as the main load-bearing members. One of the major concerns of researchers and engineers is the shear strength of reinforced concrete beams, but box girder members have the disadvantage of having difficulties in accurately placing shear reinforcement in their narrow cross-sections and densely reinforced areas. Therefore, it is of practical significance to reduce the amount of shear reinforcement allocation by adopting reasonable measures under the premise of guaranteeing the ultimate bearing capacity as well as the deformation resistance. Fiber concrete is a new composite material in the concrete matrix mixed with fibers (metal fibers, inorganic non-metallic fibers, synthetic fibers or natural organic fibers) as reinforcing materials. A large number of tests and studies have shown that the concrete matrix mixed with fibers, has a good effect of preventing the production and development of concrete cracks, the right amount of fiber in the concrete, can significantly improve the ultimate shear load capacity of concrete beams, after the peak load capacity and the ability to resist deformation. At present, there are relatively few experiments and studies on the shear resistance of fiber concrete box beams at home and abroad. Moreover, due to the complex shear mechanism of concrete structures, the limitation of statistical analysis methods and the need for full process analysis of the members, finite element analysis methods are becoming an important tool in structural force analysis. This paper is a finite element software modeling analysis of fiber concrete box beam specimens to study their shear performance. And by analyzing the effect of different fibers (steel and polypropylene fibers) and fiber admixture on the shear performance and of fiber concrete box-type beams.Box column model design.

2. Finite element modeling of box beam

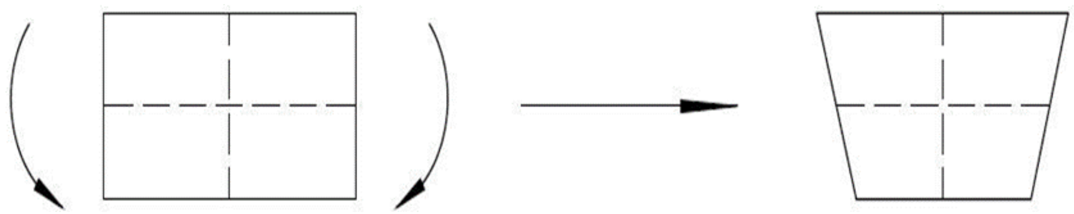
In the research process, the most common research methods are experimental analysis and theoretical calculation, but since these two methods have certain limitations, it is of practical significance to make up for their lack and deficiency with the help of finite element analysis method. Finite element analysis method refers to the simulation of the force process of the structure through computer software, and through the adjustment of various parameters such as materials, to achieve the simulation of the force process of the structure close to the real state, and finally get more accurate results.

2.1. Concrete units

Solid units need to be applied to concrete. Considering the shear performance study of the box beam as a component of this paper, hexahedral cells are selected, which have the advantage of higher accuracy. In this paper, the concrete uses 8-node hexahedral linear reduced integration three-dimensional solid unit, C3D8R unit, reduced integration that is, in every direction of the unit than the full integration (the number of Gaussian integration points used in the unit is sufficient to accurately integrate the polynomial in the unit stiffness matrix) points less than an integral point, due to Fig. 1 (the diagram of the fully integrated unit and the reduced integration unit in the solid unit) in the center of this unit Since there is only one integral point in the center of this cell, the cell is too soft due to the hourglass value problem. The selected C3D8R cell has the disadvantage of a slightly lower computational accuracy to a certain extent, but in terms of computational time this cell has fewer degrees of freedom, so it can be very good at saving computing time.



(a) Complete integration element



(b)Reduce integration element

Fig. 1 Complete integration element and Reduce integration element

2.2. Reinforcing steel units and pads

This model applies TRUSS unit to simulate reinforcement, the advantage of this unit is that it can withstand radial tension and compression, but not bending moment, this simulation ignores the bending and slip bonding of reinforcement, TRUS truss unit has two forms, two-node linear unit and three-node curved truss unit, this simulation uses three-dimensional two-node truss unit T3D2, as shown in Fig. 2. The reinforcement module is combined in the form of MergeParts to connect the reinforcement, which can improve the overall stiffness of the reinforcement and make the calculation results more accurate. Therefore, in order to prevent the occurrence of stress concentration phenomenon, it is necessary to place the mat at the loading point, and the C3D8R unit is used in the ABAQUS simulation in this paper.

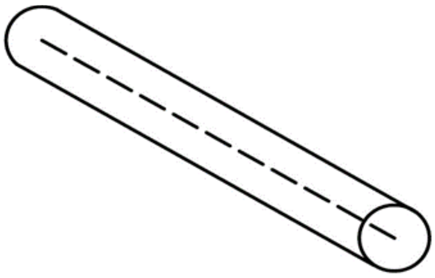


Fig. 2 Truss element types

2.3. Material parameter selection and intrinsic structure relationship

Large-scale general-purpose nonlinear finite element analysis software ABAQUS has powerful analysis capabilities compared with other nonlinear finite element analysis software, and is therefore widely used in the analysis of various properties of reinforced concrete structures. ABAQUS provides three types of concrete principal structure relationship models: Brittle Crack Concrete, Smeared Crack Concrete, and Concrete Damage Plasticity. This paper is based on the damage plasticity model (Concrete Damage Plasticity) of ABAQUS for modeling and nonlinear finite element analysis. The concrete expansion angle is 38*, the eccentricity is 0.1, and the viscous parameters are generally used in the ABAQUS dynamic analysis display solver, and the value of 0.00001 is taken for easy convergence of results.

3. Finite element model design

In this paper, 20 model beams were designed to study the effects of fiber type and fiber admixture on the shear performance of box-type beams with hoop reinforcement. The hoop reinforcement selected in this paper is 6.5mm diameter HRB335 ribbed reinforcement, the longitudinal reinforcement in the bottom plate is 16mm diameter HRB335 ribbed reinforcement, and the longitudinal reinforcement in the top and web plates are both 8mm diameter HRB235 reinforcement. The transverse reinforcement of the top slab is HPB235 steel of 8mm diameter. The mass density of reinforcement is 7800kg/m^3 and Poisson's ratio is 0.3. The mechanical properties of reinforcement are shown in Table 1.

Table 1 Mechanical property of steel

Diameter(mm)	Yield strength (MPa)	Ultimate strength (Mpa)	Modulus of elasticity (Mpa)
6.5	335	500	200000
16	350	515	200000
8	300	305	210000

The cross-sectional shape of the model beam is box-shaped, the length of the model beam is 2.3 m, the calculated span is 2.0 m, the height of the section is 0.25 m, and the effective height is 0.23 m. a is the length of the shear-span zone, and the shear-span ratios of the shear-span zone are 0.82, 1.63 and 2.45. The thickness of the web on each side of the box-shaped beam is 40mm, the thickness of the top plate is 35mm, and the thickness of the bottom plate is 40mm. The cross-sectional reinforcement of the model beam is shown in Fig. 3.

ISSN: 1813-4890

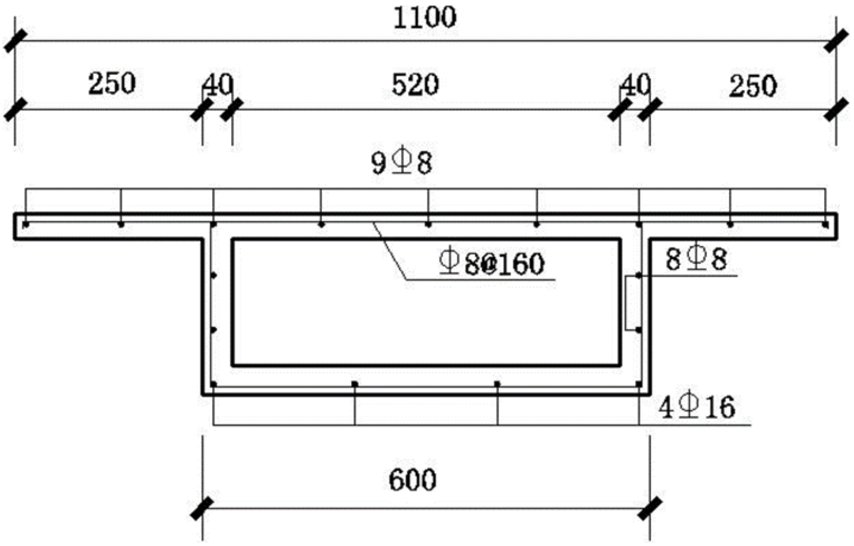
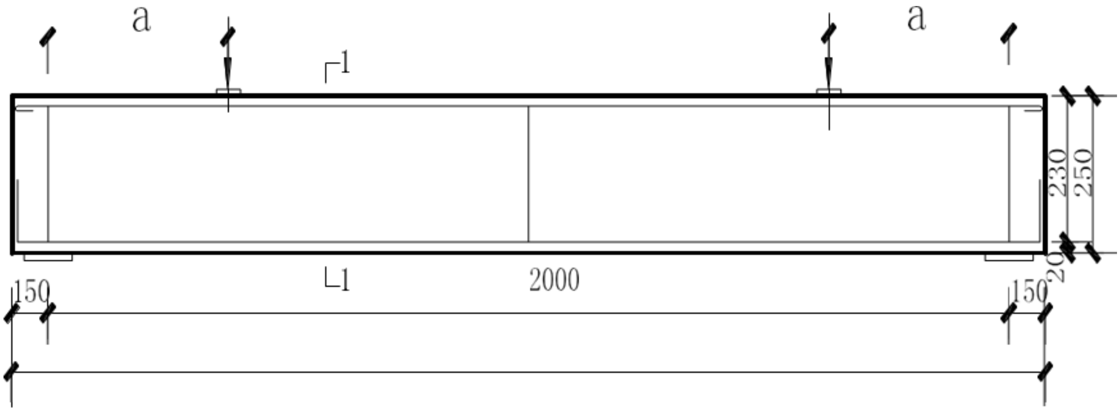
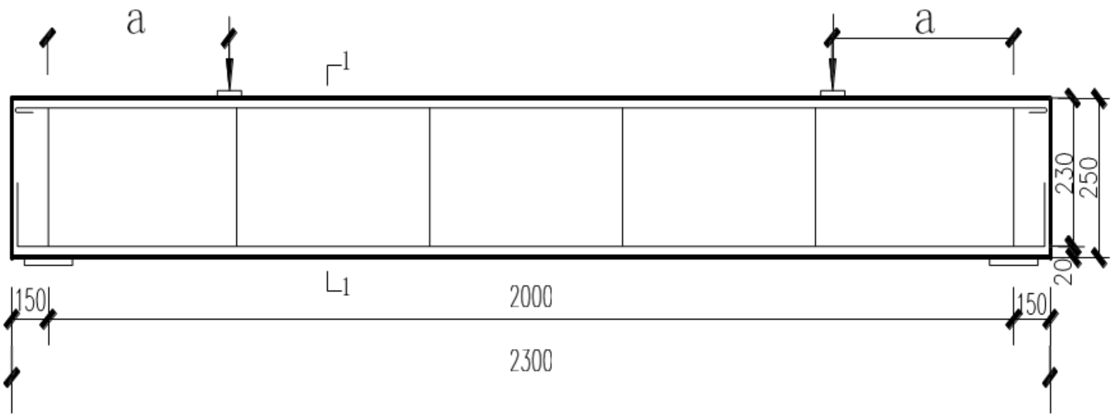


Fig. 3 Reinforcement of 1-1 section



(a) Hoop matching rate of 0.246%



(b) Hoop matching rate of 0.492%

Fig. 4 Geometry of beam

In this paper, the effect of changing the fiber type and fiber admixture on the force mechanism, damage pattern and shear capacity of the box beam members is studied. The main parameters of the members are shown in Table 2.

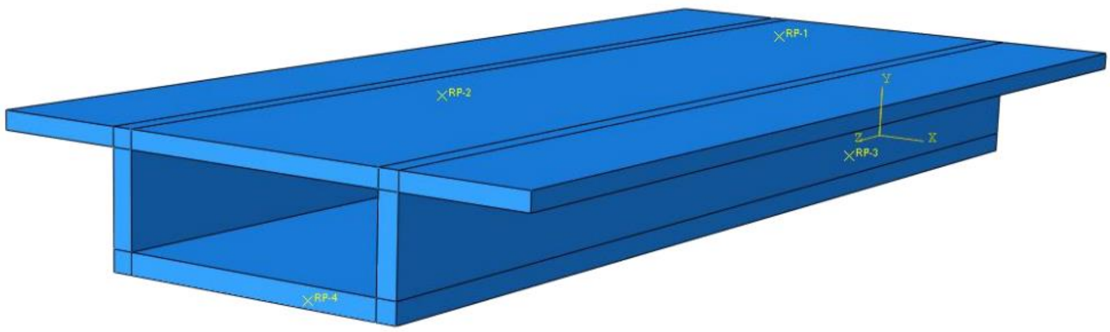
Table 2 Parameter of construction member

number		ρ_{sv}(%)	Dosing of steel fiber(%)	Polypropylene fiber dosing(%)
L1	0.82	0.246	0	0
L2	0.82	0.246	0.5	0

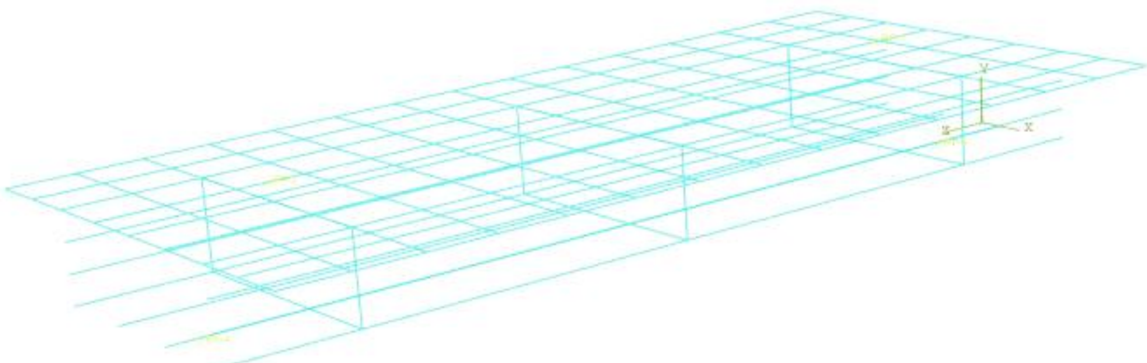
L3	0.82	0.246	0.5	0.05
L4	0.82	0.246	1.5	0
L5	0.82	0.246	1.5	0.1
L6	1.63	0.246	0	0
L7	1.63	0.246	0.5	0
L8	1.63	0.246	0.5	0.05
L9	1.63	0.246	1.5	0
L10	1.63	0.246	1.5	0.1
L11	1.63	0.492	0	0
L12	1.63	0.492	0.5	0
L13	1.63	0.492	0.5	0.05
L14	1.63	0.492	1.5	0
L15	1.63	0.492	1.5	0.1
L16	2.45	0.246	0	0
L17	2.45	0.246	0.5	0
L18	2.45	0.246	0.5	0.05
L19	2.45	0.246	1.5	0
L20	2.45	0.246	1.5	0.1

The table shows the shear-to-span ratio $\lambda = \frac{a}{h_0}$, where a is the length of the shear-to-span area and h_0 is the effective height of the member section. Hoop ratio $\rho_{sv} = \frac{A_{sv}}{b_w S_v}$, where A_{sv} is the hoop cross-sectional area within the same section, A_{sv} is the width of the box beam web and, S_v is the hoop spacing.

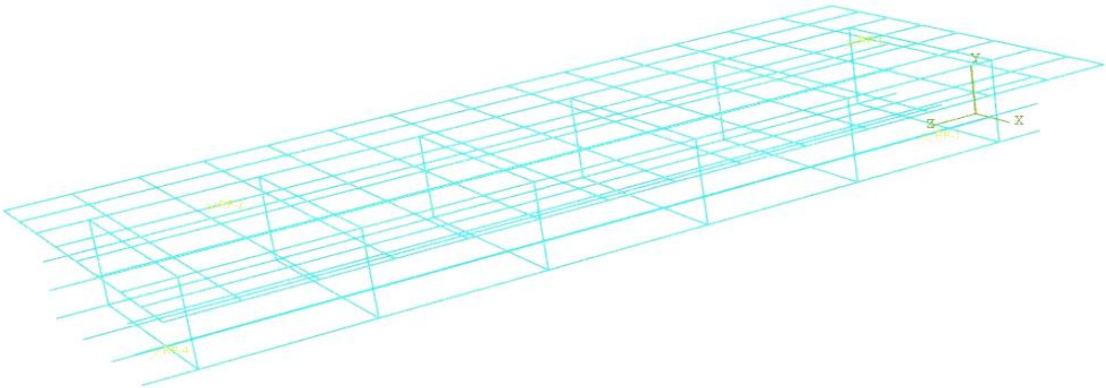
The model beam was modeled, and the finite element model of the concrete and steel skeleton is shown in Fig. 5.



(a) Concrete model



(b) Steel skeleton model with a hoop ratio of 0.246%



(c) steel skeleton model with a hoop ratio of 0.492%
Fig. 5 The finite element mode

4. Analysis of experimental results

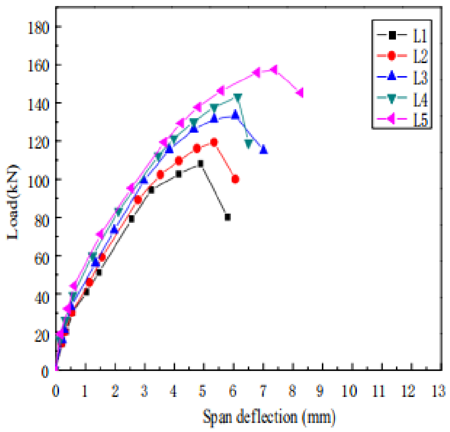
It is shown that the incorporation of fibers has a significant effect on both compressive and tensile strength of concrete. In this paper, two types of fibers (steel and polypropylene fibers) and three hoop ratios (0, 0.246% and 0.492%) are selected and five different forms of incorporation are used (SF0PF0, SF0.5PF0, SF0.5PF0.05, SF1.5PF0, SF1.5 PF0.1) to study the effect of fibers on the shear performance of the box beam for three shear-to-span ratios (0.82, 1.63, 2.45). Table 3 shows the ultimate load capacity and the mid-span deflection (ultimate displacement) corresponding to the ultimate load capacity for model beams B1 to B5 without hoops and model beams L1 to L20 with hoop ratios of 0.246% and 0.492%.

Table 3 Ultimate shear load,ultimate displacement and failure mode

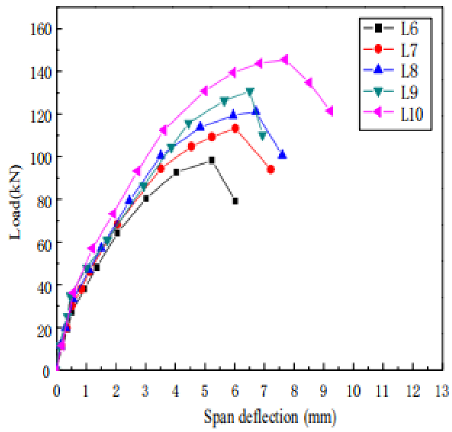
Box beam type	Ultimate bearing capacity(KN)	Ultimate displacement(mm)	Destruction mode
L1	108.16	4.87	Shear
L2	119.35	5.32	Shear
L3	133.21	6.03	Shear
L4	143.21	6.54	Shear
L5	157.32	7.34	Shear
L6	98.16	5.23	Shear
L7	113.21	6.02	Shear
L8	120.87	6.71	Shear
L9	130.51	6.83	Shear
L10	145.35	7.69	Shear
L11	152.36	5.95	Shear
L12	161.25	6.51	Shear
L13	173.25	7.54	Shear
L14	>180.34	-	Flexure
L15	>190.32	-	Flexure
L16	93.21	5.67	Shear
L17	104.54	6.21	Shear
L18	114.21	7.02	Shear
L19	117.32	7.42	Shear
L20	>137.66	-	Flexure

ISSN: 1813-4890

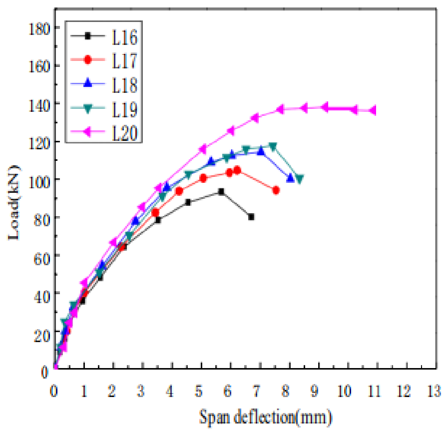
The load-span deflection curves of the fiber concrete box beam for three shear-to-span ratios (0.82, 1.63, and 2.45) at a hoop ratio of 0.246% are given in Fig 6. The following conclusions can be drawn from the changing law of span deflection of fiber concrete box girder with load: the curve can be divided into three stages, from the beginning of loading to the stage of peak load, the curve as a whole shows an upward trend, in which the curve before concrete cracking is smoother and basically shows a linear growth trend, and the model beam is in the elastic working stage; after concrete cracking, the slope of the curve becomes slower than cracking, and the stiffness of the model beam decreases; the curve reaches After the peak load is reached, the curve shows a decreasing trend and the decreasing section is shorter and the decreasing speed is faster. Therefore, the box beam model exhibits poor ductility performance during the whole shear process. This is due to the fact that the longitudinal reinforcement allocation was appropriately increased during the design stage of the model beam in order to study the shear performance of the box beam due to the variation of each parameter.



（a） λ= 0.82



（b） λ= 1.63



（c） λ= 2.45

Fig. 6 Loading-deflection curve

The load-span deflection curves of the fiber concrete box beam increase with increasing fiber type and fiber admixture, and the slope of the curve gradually increases, which means that the stiffness of the box beam increases due to the fiber admixture. After reaching the peak load, the decreasing trend of the curve is slower than that of the model beam without fiber incorporation. In the case of 2.45 shear-to-span ratio, 1.5% of steel fibers and 0.1% of polypropylene fibers (model beam L20), the curve does not show a decreasing section after reaching the peak load, and changes from brittle shear damage to ductile bending damage.

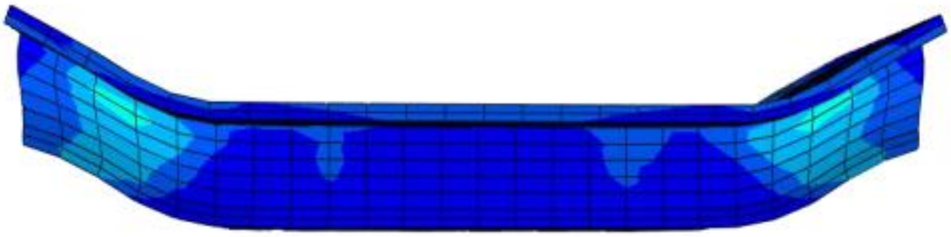


Fig. 7 Mises stress cloud chart of L5 model beam

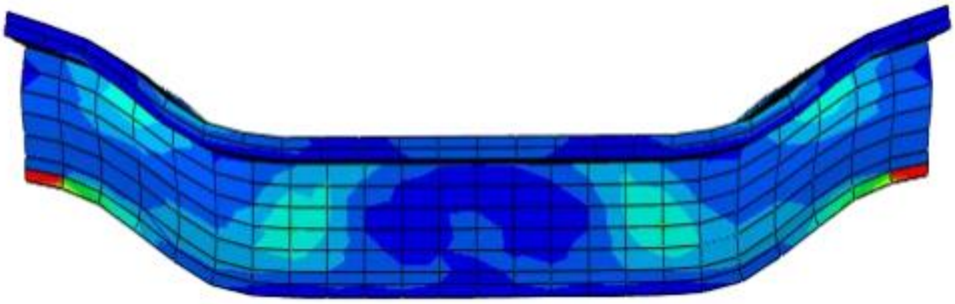


Fig. 8 Mises stress cloud chart of L15 model beam

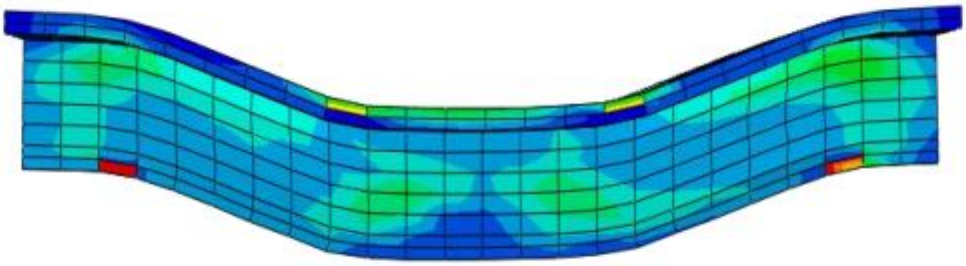


Fig. 9 Mises stress cloud chart of L19 model beam

Fig. 7 to 9 show the MISES stress clouds of model beams L5, L15 and L19, respectively. From the figures, it can be seen that the concrete stresses in model beam L5 are distributed in a "figure of eight" along the direction of the pad and loading point, and the larger stress values are mainly distributed in the shear span area, and shear damage occurs in the beam. With the incorporation of fibers, the stresses in L15 of the model beam develop toward the middle of the span and bending damage occurs. With the shear-span ratio and fiber incorporation, the bending damage occurred in the model beam L19. The descending section of the box beam at three shear-span ratios with 1.5% steel fiber admixture and 0 polypropylene fiber admixture (L4 and L9) falls faster and has a steeper descending trend than the model beam with 0.5% steel fiber admixture and 0.05% polypropylene fiber admixture (L3 and L8). Meanwhile, combined with the bending damage of the model beam L20, it can be concluded that the mixing of fibers in the concrete body has a very obvious effect on the shear ultimate load capacity and deformation capacity of the box beam and has a certain influence on the damage mode of the box beam; the effect of mixing fibers is more obvious than that of mixing single fibers, which indicates that mixing steel and polypropylene fibers in concrete has excellent positive mixing effect.

5. Conclusion

The ultimate load capacity of the box beam increases with the fiber incorporation, and the ultimate load capacity increases with the increase of fiber incorporation. At the same time, the ultimate displacement of the box beam is improved with the fiber admixture, and the ultimate displacement is smaller for model beam L4 and L3 in Fig. 20 and model beam L9 and L8 in Fig. 24 for the shear-to-span ratio of 1.63 and 2.45, so it can be concluded that the mixed fiber admixture is better than the single fiber admixture in improving the ultimate displacement of the box beam. The reason why the falling section and ultimate displacement of the model beam L4 (1.5% steel fibers and 0 polypropylene fibers) and L3 (0.5% steel fibers and 0.05% polypropylene fibers) do not conform to the above-mentioned rule in the case of 0.82 shear-to-span ratio is probably because the mixing effect of fibers is not obvious in the case of small shear-to-span ratio. In this case, the main factor affecting the shear performance of the box beam is the shear-to-span ratio.

Acknowledgments

Innovation and Entrepreneurship Training Program Project of North China University of Science and Technology(T2022226).

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