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Research Article

Prestressed Steel Reinforced Concrete Frame Applied to Outer-jacketing Structure and its Restoring Force Model Based on IDARC

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Abstract: A new style of frame structure made up of encased H-shape steel prestressed concrete composite beams and angle-steel concrete columns with 4 or 8 angle-steels is put forward and joint constructions of the frame are given in detail. This frame is fit for reconstructing the existing building using outer-jacketing structures for story-adding. On the basis of analyzing application of PARK trilinear restoring force model in IDARC analysis software, recommended restoring force models of beams and columns of prestressed steel reinforced concrete frame based on IDARC in seismic response analysis are given as well as the method regarding frame joint as rigid region. It provides basis for elastic-plastic seismic response analysis of prestressed steel reinforced concrete frame applied to outer-jacketing structure for story-adding**.**

Keywords: Angle steel concrete column, IDARC, outer-jacketing structure for story-adding, prestressed steel reinforced concrete frame, restoring force model

INTRODUCTION

At present, with the transition of China's construction industry from primarily new construction to new and retrofit construction, the reconstruction of the existing building using outer-jacketing structures for story-adding has already become one of the hot issues in China's city construction (Zheng *et al*., 2005). This study constructs a new style of frame structure made up of encased H-shape steel concrete composite beams and angle-steel concrete columns, if necessary, the beams for frame can be exerted prestressing effect. The frame structure can bear self-weight in the process of the construction and it is convenient for layout and anchorage of prestressing tendons, so it is suitable for the reconstruction of the existing building using outer-jacketing structures for story-adding. Restoring force models of encased H-shaped steel prestressed concrete composite beam and angle steel concrete composite column are the foundation of elastic-plastic seismic response analysis of the frame structure by IDARC.

In view of the little research of restoring force characteristics of angle steel concrete column, so it is suggested that reinforced concrete columns replace angle steel concrete column when the restoring force model is established. The restoring force model of frame beams is established according to two stages for the prestressing tendons of encased H-shaped steel concrete composite beam.

THE SELECTION OF OUTER-JACKETING STRUCTURE SYSTEM

Combined with outer-jacketing reconstruction project of Suifenhe Qingyun market, the idea of the construction phase self-supporting floor was put forward (Zheng *et al*., 2005), that is, during the construction self-weight of frame beams and construction loads are beared by the prestressed steel truss and in-service phase the added loads are taken by outer-jacketing framework. The floor system can not only bear new construction loads and ensure the normal use of original building in the construction process, but also achieve the integration of force structure and construction measures, so saving investment and reducing construction period can be achieved. However, although the self-supporting floor system during the construction phase has been applied in several projects, some problems still exist.

By composite frame instead of concrete frame, outer-jacketing structures for story-adding can be constructed faster and the construction period will be reduced, at the same time, it can be avoided that construction load is transmitted to the original roof during the construction phase. However, because the original housing generally is wider, so it is necessary to exert prestressing to steel frame composite beam or steel reinforced concrete beam. If solid-web steel reinforced concrete columns and beam are adopted, it is difficult to arrange and anchor prestressed tendons.

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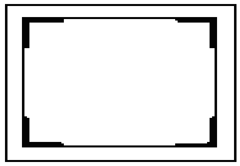


Fig. 1: Concrete column with four angle-steels

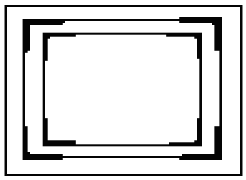
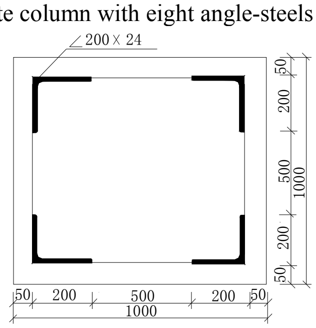
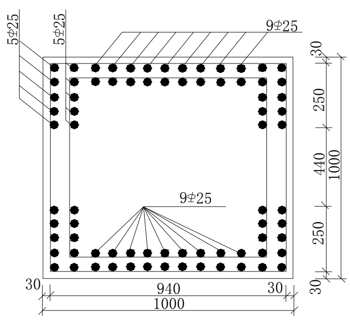


Fig. 2: Concrete column with eight angle-steels



(a) Angle steel concrete column



(b) Equivalent reinforced concrete column

Fig. 3: Sections of two kinds of columns

Therefore we recommend that outer-jacketing prestressed steel reinforced concrete frame is formed by H-shape steel prestressed concrete composite beam as frame beam and the angle steel concrete column made of 4 or 8 angle steel as frame column, H-shape steel through the gap in the angle steel. The cross-section view of the column with four and eight angle steels is shown in Fig. 1 and 2 respectively. The longitudinal angle steel of column is welded with horizontal stirrups to form the spatial steel skeleton; it can share external loads with constraint concrete. There is no more longitudinal reinforcement outside the angle, so the concrete protective layer of angle steel skeleton can be reduced and is roughly the same as ordinary reinforced concrete column. Not only can the lever arm of the angle steel increase to make the column play a greater

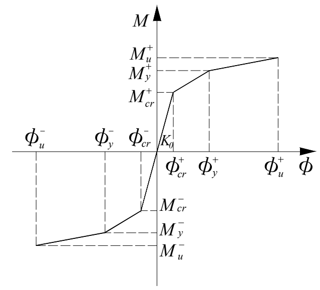


Fig. 4: Skeleton curve

role, but also it is easy to chisel away smaller protective layer concrete and weld a variety of small components.

The area of four angle steels with a wide of 200 mm and a thickness of 24 mm is roughly equivalent to 76ø25 steel bar, so it is feasible that angle steel concrete columns are adopted as outer-jacketing structure frame column. According to the principle of the same area, constant neutral axis and strong, angle steel concrete columns with four angle steels and equivalent reinforced concrete column are shown in Fig. 3, it can be seen from Fig. 3, angle steel is used instead of steel bar in the outer-jacketing frame column, this method solve the thorny problem, that is, it is difficulty for longitudinal reinforcement to layout at the beam-column joints.

PARK THREE LINEAR RESTORING FORCE MODEL IN IDARC

At present, three linear restoring force models which are put forward by Park *et al*. (1987) are recognized as the most comprehensive model, this model can better consider the pinch effect and strength and stiffness degradation phenomenon and it is applied to the structural nonlinear analysis program IDARC. The key of the program application is that the restoring force model of the structural members is accurately reflected. Restoring force model of structural members in the IDARC program includes the skeleton curve and hysteretic rules, the skeleton curve can be achieved in two ways: one is that the skeleton curve is determined by the program through inputting the axial force, stress-strain relationship of longitudinal reinforcement and concrete, sectional reinforced area, distance of the centre of the steel bar to cross-sectional surface, the diameter of the stirrup, stirrup spacing and constraint effect (Valles *et al*., 1996); the other is that skeleton curve of structural members restoring force model is input directly by calculating, the skeleton curve is shown in Fig. 4. $M_{cr} \pm$ and $\emptyset_{cr} \pm$ stand for forward and reverse cracking

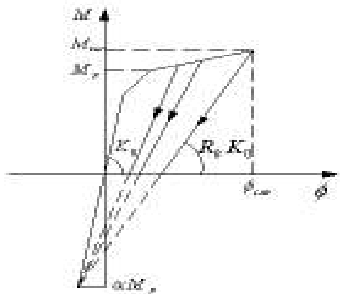


Fig. 5: Stiffness degradation during unloading

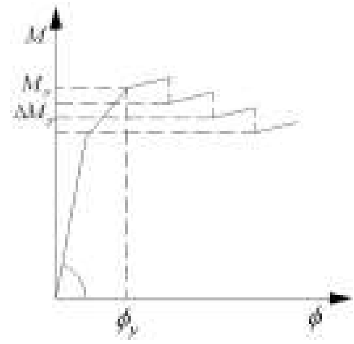


Fig. 6: Strength degradation

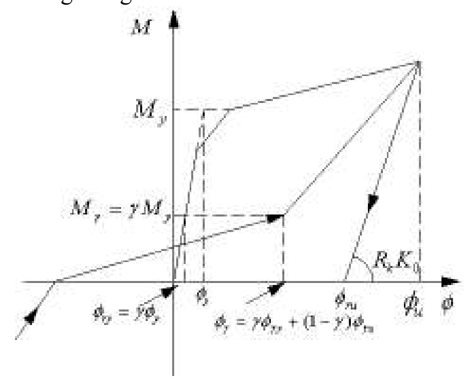


Fig. 7: Slip and pinch degradation

moment and the corresponding crack curvature; $M_y \pm$ and $\varphi_y \pm$ stand for forward and reverse yield moment and the corresponding yield curvature; $M_u \pm$ and $\varphi_u \pm$ stand for forward and reverse the limit bending moment and the corresponding ultimate curvature.

Above anyone manner is adopted to form skeleton curve for restoring force model, the hysteretic rules of restoring force model need to be determined. Hysteretic rules include stiffness degradation, strength degradation, slip degradation and hysteretic mode. The hysteretic rules of different construction members can be simulated realistically by setting the stiffness degradation parameters (α), strength degradation parametersm (β_1, β_2), the slip degradation parameters (r) and selection of hysteretic mode. The physical meanings of degradation parameters, calculation formula and the hysteretic mode are as follows:

Stiffness degradation: Stiffness degradation of structural members restoring force model at unloading stage is often referred as the stiffness degradation. The initial stiffness line is reverse extended to a point that the vertical ordinate is αM_y and unloading line point to the point until it is intersected with $\emptyset$ axis, then reverse loading line point to the maximal point which is previously reached. If the previous maximum point is in elastic range, it will point to the crack point. Forward stiffness degradation diagram is shown in Fig. 5. Calculation formula of forward and reverse unloading stiffness degradation coefficient is as follows:

$$R_k^{+/-} = \frac{M_{cur}^{+/-} + \alpha M_y^{+/-}}{K_0^{+/-} \phi_{cur}^{+/-} + \alpha M_y^{+/-}} \tag{1}$$

where,

$M_y^{+/-}$ = Forward and reverse yield bending moment

$M_{cur}^{+/-}$ = Forward and reverse the unloading point bending moment

$\emptyset_{cur}^{+/-}$ = Forward and reverse the unloading point curvature

α = Stiffness degradation parameter, αε[2,200] $K_0^{+/-}$

$K_0^{+/-}$ = Forward and reverse initial elastic stiffness

$R_k^{+/-}$ = Forward and reverse unloading stiffness degradation coefficient

Strength degradation: Strength degradation is used to describe the phenomenon which skeleton curve of structural members reduces under cyclic loading, forward strength degradation is shown in Fig. 6. The formula is as follows:

$$M_y^{+/-} = M_{y0}^{+/-}\left[1-\left(\frac{\phi_{\max}^{+/-}}{\phi_u^{+/-}}\right)^{\frac{1}{\beta_1}}\right]\left[1-\frac{\beta_2}{1-\beta_2}\frac{H}{H_{ult}}\right] \tag{2}$$

where,

$M_y^{+/-}$ = The yield bending moment after forward and reverse degradation

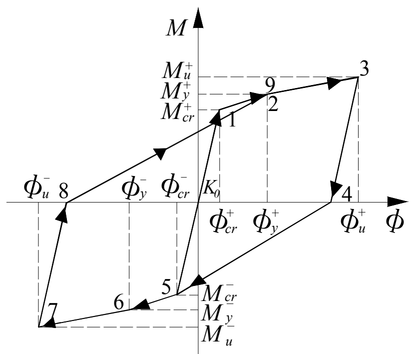
$M_{y0}^{+/-}$ = Forward and reverse initial yield bending moment

$\emptyset_{max}^{+/-}$ = Forward and reverse maximum curvature that hysteresis loop reached

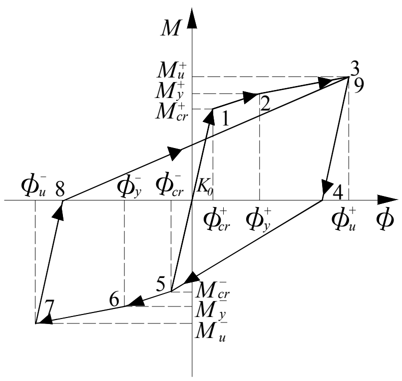
$\emptyset_n^{+/-}$ = Forward and reverse limit curvature

β_1 = The degradation parameter based on the ductility

B_2 = The degradation parameter based on the energy; β_1, $\beta_2 \in [0.01,1]$



(a)Yield towards method



(b) Vertex towards method

Fig. 8: Hysteretic modes in IDARC

H = Absorbed energy by complete hysteresis loop
H_{ult} = Energy which the hysteresis loops forward and reverse the ultimate bending moment point and limit curvature point exist can absorb without any degradation

Pinch and slip degradation: Pinch and slip degeneracy phenomenon will be produced in restoring force model of structural member because the concrete crack and close. In Park model, parameter γ is used to describe slip degradation and forward slip degradation is shown in Fig. 7. It can be seen from the Figure, when γ is equal to 1, no slip degradation. M_r and ϕ_r are the bending moment and curvature values corresponding to the first segment end point for considering crack effect and the physical meaning of other symbols are the same with above meaning.

Hysteresis mode: Two kinds of hysteretic mode are provided in IDARC restoring force model of members, they are yield toward method with considering the slip effect and vertex toward method without considering slip effect (Valles *et al*., 1996) and both are shown in Fig. 8. 1-9 represent the process of hysteresis and the symbols physical meaning are same with above ones. Forward load stiffness which is 8-9 process is shown in Fig. 8, it is determined respectively according to the yield toward method and vertex toward method. Reverse loading stiffness as 4-5 process is determined according to the following method, if the previous largest point in elastic range, then it will point to crack point, on the contrary it can be determined by the yield toward method and vertex toward method.

RESTORING FORCE MODEL OF ANGLE STEEL CONCRETE COLUMN BASED ON IDARC

Determination of the skeleton curve: In IDARC, skeleton curve can be built by first way based on the constitutive relationship of materials for reinforced concrete column. From Fig. 3, angle steel concrete columns which are adopted in this study can be regarded as reinforced concrete column, therefore, according to the first way the skeleton curve of angle steel concrete columns is built. Skeleton curve can be determined by IDARC program and the restraint effect are relevant to type of stirrups in the section. The value is shown in literature (Valles *et al*., 1996). Constitutive relation ship of concrete and steel in IDARC is shown in literature (Valles *et al*., 1996).

Determination of the four parameters and hysteretic mode: In IDARC, the four parameters in hysteretic rules of restoring force model of member were respectively given four different degradation cases and the corresponding values, the four different degradation cases were severe degeneration, medium degradation, slight and no degradation. In IDARC, it is recommended that medium degeneration can be used for the four parameters of the restoring force model of the reinforced concrete column. In this study, the angle steel concrete column can be regarded as reinforced concrete column and meet the above requirements, therefore, medium degradation can be used for the four parameters of restoring force model, the corresponding values is 10, 0.3, 0.15, 0.25. The yield toward method considering the slip effect is adopted in hysteretic mode.

RESTORING FORCE MODEL OF COMPOSITE FRAME BEAM BASED ON THE IDARC

Determination of the skeleton curve: In IDARC, skeleton curve of H-shape steel prestressed concrete composite frame beam can not be given directly based on the constitutive relationship of steel, concrete, steel bar and prestressing tendon. In view of this, we use the second way to establish skeleton curve of the composite frame beam.

For the prestressed reinforcement of H-shape steel prestressed concrete composite frame beam, it can be considered in two stages: the first stage is from tension to the effective prestressing σ_{pe}, the idea of this stage is prestressing force is equivalent for external loads and is

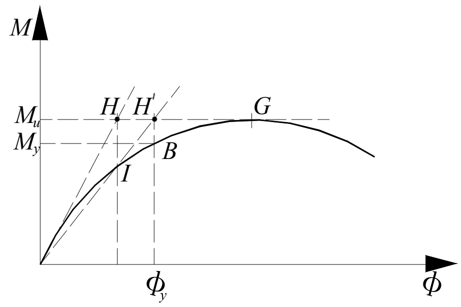


Fig. 9: Determination of yield point using current yield moment method

applied to the structure. The second phase is prestressed reinforcement is equivalent for non prestressed reinforcement of tensile yield stress for f_{py} -σ_{pe} and providing resistance together with additional configuration steel bar for the members.

This study used plane section assumes and sectional strip method, reckoned in the affection of axial force generated by the tensioning prestressed reinforcement and the role of framework beam concrete flange, compiled the calculation program for moment-curvature relationship ($M-\phi$ curve) of the H-shape prestressed concrete composite beam arbitrary cross-section and then the forward and reverse crack moment and the corresponding curvature value, the forward and reverse the ultimate moment and curvature values on arbitrary cross-section skeleton curve can be obtained by the process. The forward and reverse cracking moment corresponds to the moment when the concrete on the upper and lower edge of the concrete frame beam was pulled cracking. The experimental results of steel concrete beams loaded property in literature (Zhang, 2005; Msallem *et al*., 2010) show that it is not big difference between the load of the steel concrete beam when the concrete is crushed and peak load, so the bending moment and the corresponding curvature when upper and lower edge concrete of frame beam reached the ultimate compressive strain was designated as forward and reverse the limit bending moment and the ultimate curvature. The forward and reverse yield moment and corresponding curvature values are determined according to the general yield moment method and it is shown in Fig. 9. Tangent was made through the origin point O of M-∅ curves and intersected with the horizontal line which is through horizontal ultimate bending moment G point at the H point; vertical was made from H point and intersected curve M-∅ at I point; O and I were linked, then extended and intersected with HG at H', vertical was made from H' point and intersected curve M-∅ at B point, B point was yield point, its level ordinate is the yield curvature and the vertical ordinate is yield bending moment, reverse similarly.

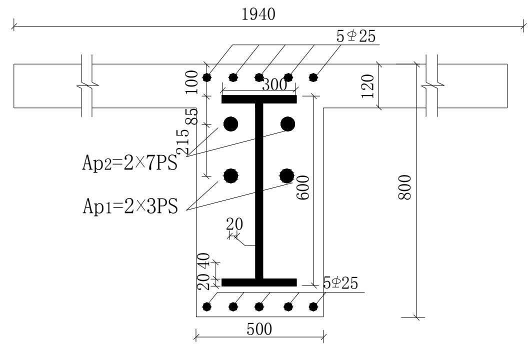


Fig. 10: Section of encased H-shape steel prestressed concrete composite frame beams at support

Determination of four parameters and hysteretic mode: It is the crucial link for describing the restoring force model for H-shape steel prestressed concrete composite frame beam in the IDARC, that four parameters and the hysteretic model is accurately determined. The stiffness degradation parameters are most important, so the detailed description is shown as follows: Unloading stiffness degradation coefficient calculation formula of members restoring force model in IDARC is shown in formula (1), for forward unloading stiffness degradation coefficient, the followings can be obtained from the Fig. 6:

$$M_{cur} = (\frac{M_u - M_y}{\phi_u - \phi_y})(\phi_{cur} - \phi_y) + M_y \quad (3)$$

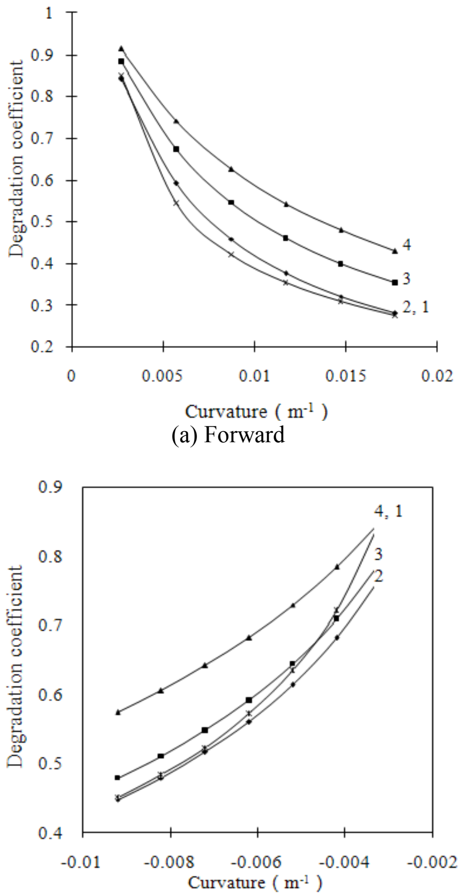
where, physical significance of M_y, M_u, M_{cur}, ϕ_y, ϕ_u and ϕ_{cur} are the same as the former. We will handle above equation into unloading stiffness degradation coefficient formula (1), When α is a fixed value, the unloading stiffness degradation coefficient R_k is the function of, it is recorded as function 1. Unloading stiffness degradation coefficient formula of solid-web steel concrete frame beam restoring force model is given in Literature (Xue and Zhao, 2000), that is:

$$R_k = 0.85 \times (\phi_{cur} / \phi_y)^{-v} \quad (4)$$

The suggested value of v is 0.6. R_k is also function of ϕ_{cur} and is recorded as function 2. It is required in literature (Xue and Zhao, 2000) that steel section size of solid-web steel concrete frame beam and frame beam cross section size should be similar and coordinate. While In this study the H-shape steel concrete composite frame beam is Coincide with the above requirements, therefore, the H-shape steel concrete composite frame beam unloading stiffness degradation coefficient formula is taken as function 2. By selection α the two function curves about R_k are in

Table 1: Data of skeleton curve for section

Point	$M_{cr\pm}$ (N/m)		$\emptyset_{cr\pm}$ (m^{-1})		$M_{y\pm}$ (N/m)		$\emptyset_{y\pm}$ (m-1)		$M_{u\pm}$ (n/m)		$\emptyset_{u\pm}$ (m-1)	
Value	3.6e5	-5.7 e5	2.4 e-4	-3.5e-4	2.5e6	-2.5e6	2.7e-3	-3.2e-3	3.2e6	-3.3e6	8.5e-3	-9.8e-3



(a) Forward

(b) Reverse

Fig. 11: Stiffness degradation coefficient curves of frame beams

good agreement. Similarly, the above two function curves for reverse unloading stiffness degradation coefficients R_k are in good agreement through selection the same α . Forward and reverse unloading stiffness degradation coefficient of restoring force model of H-shape steel prestressed concrete composite frame beam can be described in IDARC program through selecting accurately α value.

Supporting section of H-shape steel prestressed concrete composite frame beam in one-layer top of an outer-jacketing structure is shown in Fig. 10. We take it for an example to illustrate how to select stiffness degradation parameter α . Frame beam medio-prestressed Reinforcement (Ap1 = 2×3 PS) is arranged by single parabolic link, Upper prestressed reinforcement (Ap2 = 2×7 PS) is arranged by three parabola links. The data shown in Table 1 are the date which correspond to forward and reverse directions crack point and extreme point of the frame beam Support section skeleton curve and is calculated by computer program, the yield point data is determined by general yield moment method.

Based on the function 2, forward and reverse unloading stiffness degradation coefficient curve of the above section restoring force model is shown as curve 1 in Fig. 11a and b. Based on the function1, in IDARC, when α is 2.5, 4 and 6, the forward and reverse unloading stiffness degradation coefficient curve of the section restoring force model is shown as curve 2, 3 and 4 in Fig. 11a and b.

From Fig. 11 we can see, forward and reverse unloading stiffness degradation coefficient curve 2 is good agreement with unloading stiffness degradation coefficient curve1 which based on function 2, when α is equal to 2.5.

It is known that solid-web steel concrete frame beam *P*-Δ hysteretic curve is plump and spindle-shaped (Chen, 2011), skeleton curve strength degradation is relatively slow, therefore, the strength degradation parameters β_1, β_2 of above frame beam arbitrary cross section restoring force model can be respectively selected slight degradation and sliding degradation parameters γ are considered to no degradation in the IDARC. The frame beam shown in Fig. 11 is accordance with the requirements for solid-web steel concrete frame beam, so the strength degradation parameters β_1, β_2 and γ of support section restoring force model can be taken as 0.15, 0.08, 1 respectively. Vertex toward method without considering slip effect is used in hysteretic mode.

PROCESSING ON JOINT REGION OF OUTER-JACKETING FRAME IN IDARC

In IDARC, In order to show framework node area, Column and beam interchange are need to give domain area length, Column domain area length take half of the beam section height, beam domain area length take half of the Column section height.

CONCLUSION

- This study constructed a type of frame structure with H-shape prestressed concrete composite beams as the frame beams and angle steel concrete columns equipped with 4 or 8 angle steel as frame columns, then the structural form of frame nodes is given. The frame structure is suitable for the reconstruction of the existing building using outer-jacketing structures for story-adding.
- Based on the IDARC, restoring force models of H-shape prestressed concrete composite frame beam and angle steel concrete are proposed.

- Because the span of outer-jacketing frame is larger, the original roof cannot bear outer-jacketing construction loads, so frame beams construction load is borne by H-shape steel beam (or prestressed H-shape steel beam) through hanging formwork construction technology. In service stage, the follow-up load is borne by H-shape steel prestressed concrete composite beams. The restoring force models of H-shape steel prestressed concrete composite beams on the two stages are needed to study.

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