Modern Applied Science

SE www.ccsenet.org/journal.html

Vol. 2, No. 3 May 2008

Analysis of Unbonded Prestressed Concrete T-type

Beam's Dynamic Characteristics

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Abstract

Prestressed force's impacts on simple T-type beam's vibration such as vertical bending, horizontal bending, torsioning, etc., were researched in this paper. It also separately sets up beam element model basing on prestressed concrete equivalent load principle and solid element model taking slippage between prestressed reinforcing steel bar and concrete into account, and developed simulation analysis on two linear steel bar lay-outs & two curving ones. The computed results of different models & different steel bar lay-outs were analyzed and contrasted with each other, as produced simple T-type beam's frequency influencing factors.

Keywords: Prestressed beam, Unbonded, Equivalent load, Dynamic characteristics

1. Introduction

Unbonded prestressed T-type beam is widely applied in engineering structure for research on its dynamic characteristics is of great engineering significance. Domestic and overseas scholars' understandings of prestressed force's effect on concrete beam's dynamic characteristics are different. The early theory thought that frequency increases along with prestressed force's reduction, and prestressed force is sensitive to lower frequency. Saiidi M, Douglas B, Feng S carried on indoor model experiment on simple rectangular solid sectioned beam with prestressed force's increase at its centre. Their conclusion was that beam's bending basic frequency increases along with prestressed force's influence on frequency is relatively small. Through theoretical analysis A.Dall, Asta and Dezi thought that prestressed force's influence on frequency is small, and could be overlooked. Abraham, etc. thought that prestressed force's influence on beam's vibration modality is quite small.

Numerous researches indicate that besides prestressed force's strength, prestressed beam's mode is more influenced by shape of section, boundary conditions, lay-out of prestressed steel bars, elasticity coefficient, section's moment of inertia, crack size, distribution and so on.

The present analysis mainly concentrates on vertical vibration. Because of T-type beam's particularity, its vibration characteristics like horizontal bending, torsioning and so on are necessary to be taken into account. This article separately sets up beam element model and solid plus link element model of simple T-type prestressed beam utilizing equivalent load method & initial stress method. Furthermore, different lay-outs of reinforcing bars are computed & analyzed.

2. Prestressed equivalent load

The prestressed force in concrete's section of post-tensioning prestressed components comes from extrusion between prestressed steel bars & concrete and polar anchor's collected load. So function of prestressed force could be equivalent to a group of load acting on the concrete structure, as is equivalent load usually called. To separate prestressed force from concrete components and to analyze separately when computing exact equivalent load could derive the equivalent load according to equilibrium conditions. As to computation formula of equivalent load caused by simple beam's prestressed force: component of polar collected force N_p produced by prestressed steel bars at axial direction is $N_p \cos \theta$; prestressed beam's striding height is usually large; angle θ of prestressed steel bars' tangent and axis is small; $N_p \cos \theta \approx N_p$, polar axial force N_p^* is equivalent to N_p . When polar force simplified to direction of axis, it produces equivalent eccentric torque $M_p^* = N_p \cos \theta \cdot e \approx N_p e$. As to inter-segment, extrusion between prestressed steel bars and concrete produces equivalent distributing force. According to the equilibrium condition, $q(x)=N_p d^2 y/dx^2$ could be obtained. As to straight pole of constant section, the prestressed equivalent load is related with prestressed steel bars' effective tension, polar eccentric distance and prestressed steel bars equation's second differential, and irrelated with structural form.

As to straight line reinforcing bars, the prestressed steel bars equation's second differential is zero; the equivalent inter-segment load is zero, viz. the straight line prestressed steel bars produce no extrusion on concrete at the vertical direction.

The parabola reinforcing bars whose rise is f: the prestressed steel bars equation $y = ax^2 + bx + c$. According to geometric relations: $a = 4f/L^2$. It's obvious that when prestressed steel bars are dual parabola reinforcing bars, the equivalent inter-segment load is a constant.

Fig. 1 is concrete simple beam's equivalent load of straight line reinforcing bars and dual parabola reinforcing bars. The prestressed steel bars' effective tension N_p , the eccentric distance is e_n , f is the parabola's rise.

3. Dynamic characteristics computation and analysis

3.1 Model's construction

Model's parameters: Simple beam's length 24m; size of the section is shown in Fig. 3 & Fig. 4. The concrete's elastic coefficient is 3.8×104 MPa, the density is 2600 kg/m3, steel bar 210 GPa, the density is 7800 kg/m3. The two straight line steel bars' lay-outs and two curve steel bars' lay-outs are considered separately. The situations in which effective prestressed forces exerted are 0, 1000 kN, 2000 kN and 3000 kN.

The available element forms equivalent load method may adopt are mainly the BEAM series, the SHELL series and the SOLID series. Taking this method's characteristics into account, the structural components adopt space beam element BEAM188 to construct the model. The BEAM188 element is good to analyze beam structure from thin-tall to medium thick & length. The element bases on the first-phased cut & distortion theory and Timoshenko Beam Structural Theory, taking effect of cut & distortion into account. Merits of equivalent load method are simpler model construction, direct model construction irrespective of specific position of steel bars, easier grid division and ease of obtaining structure's overall effect under function of prestressed force. But it's unable to take distribution & direction of steel bars' function to concrete into account.

In the initial stress method, unbonded prestressed concrete components' unbonded steel bars' slippage from concrete shouldn't be neglected; components are divided into two parts of reinforced concrete and prestressed steel bars when constructing the model; the prestressed steel bars are simulated by LINK8 element, and the concrete is simulated by SOLID95 element. SOLID95 is higher element form of SOLID45 (3-dimensional 8 nodes), defining 20 nodes with each one having 3 planar motion degrees-of-freedom. This element permits irregular form, reducing no accuracy. So it especially suits models whose boundaries are curve. Furthermore, its displaced form's compatibility is good. Exertion of the prestressed steel bars' prestressed force adopts initial stress method. Connection of two parts is realized through degree-of-freedom's coupling. The nodes of LINK8 and SOLID95 are all only having planar motion degree-of-freedom along directions of three coordinate axes; when simulating the unbonded form, the prestressed steel bars' longitudinal planar motion degree-of-freedom is released; the other two directions' nodes' degrees-of-freedom need to be coupled to guarantee same value of the corresponding ones. As to situation of curved prestressed steel bars, sufficient elements should be defined to guarantee prestressed steel bars' proper radians. Moreover, cushions need to be arranged to solid elements when exerting restriction or to partially strengthen them to avoid stress concentration brought by local distortion.

Fig. 5 shows frequencies by two model construction methods with no prestressed force exerted. In the figure, V, H, T & L are respectively vertical bending, horizontal bending, torsioning and axial expansion. The computed frequencies and lineups by two methods are consistent too each other. The lower self-vibration frequencies of horizontal bending & axial expansion on the beam plane surface especially fit well.

3.2 Frequency's variation under function of prestressed force

Table 1. shows the computed frequency's variation along with prestressed force's alteration basing on equivalent load method and utilizing beam element model construction. It could be seen that form of reinforcing bars influences little to the result. Equivalent load method only takes prestressed force as exterior load to exert on the structure, and is unable to take distribution and direction of steel bars' action to concrete into account. Different lay-outs of steel bars only cause the exerted load's change while this kind of change's influence on the prestressed beam's frequency is slight.

The result also reveals that the beam's every phase's frequencies take on a linear trend of decreasing along with the prestressed force's increase, and the lower frequencies obviously vary more greatly than the higher frequencies. This is consistent with traditional computational theory. The Eluer-Bernoulli beam theory could be referred to support: Supposing prestressed beam is isotropic simple beam under axial force's action, the beam's curving differential equation

is

$$p(x,t) = \frac{\partial^2}{\partial x^2} \cdot \frac{EI\partial y^2}{\partial x^2} + \frac{N\partial y^2}{\partial x^2} + \frac{m\partial y^2}{\partial t^2}$$
(1)

To solve it,

$$\omega_n = \frac{n^2 \pi^2}{l^2} \cdot \left(1 - \frac{Nl^2}{n^2 \pi^2 E_c I_c}\right)^{1/2} \cdot \left(\frac{E_c I_c}{m}\right)^{1/2} \tag{2}$$

In the formula, N is the effective tensioning force; EI is the beam's flexural rigidity; ω_n is the beam's n-phased frequency; l is the beam's span; m is the unit length mass. From the formula it could be seen that prestressed simple beam's frequencies reduce along with the axial force's increase.

Table.2 is the result computed by initial stress method. It indicates that lay-out of steel bars affects beam's frequency greatly. As to situation of reinforcing bars' disposed at straight line's centroid, the frequencies increases along with prestressed force's decrease. But to eccentric straight line reinforcing bars and curve reinforcing bars, when prestressed force increases, variation of different phases' frequencies is not the same. Vertical vibration, torsioning and axial expansion's basic frequencies decrease along with prestressed force's increase; horizontal vibration's basic frequencies take on tendency of increase. Some higher frequencies also increase along with prestressed force's increase. But in brief, the computed frequencies obtained through prestressed force method using model of solid steel bars receive less influence from prestressed force; especially the basic frequencies at different directions, they all change below 0.12%. Only change of torsioning's higher frequency is relatively greater, but the utmost is no less than 2%.

4. Conclusion

Model of prestressed simple beam constructed according to equivalent load mechanism cannot take distribution and direction of steel bars' action to concrete into account. So different lay-outs of steel bars' influence on the prestressed beam's frequencies is slight. And because the model adopts beam element, the beam's frequencies appear consistent with traditional computational theory: Increase along with prestressed force's decrease, and the lower frequencies obviously alter more greatly than the higher frequencies.

As to solid, isotropic and non-dehiscenced element, the computed result demonstrates that prestressed force's influence on beam's dynamic characteristics is weak and mainly decided by lay-out of prestressed steel bars. If prestressed steel bars are eccentric straight linear or parabolic disposed, the frequencies possibly increase along with prestressed force's increase, but the alteration scope is small. The conclusion drawn from model of solid steel bars tallies with presently existing tentative data, and is still coincident with actual ones.

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Table 1. Frequency varying proportion by equivalent load method

	modality	V1	H1	V2	T1	T2	V3	H2	T3	L1	Н3
	prestress	Frequency variation (%)									
Linear pattern 1	1000kN	-0.976	-0.342	-0.250	-0.055	-0.188	-0.118	-0.120	-0.057	0.000	-0.094
	2000kN	-1.963	-0.684	-0.506	-0.117	-0.375	-0.235	-0.243	-0.113	-0.003	-0.187
	3000kN	-2.957	-1.029	-0.756	-0.178	-0.563	-0.353	-0.362	-0.173	-0.005	-0.283
Linear pattern2	1000kN	-0.976	-0.422	-0.250	0.018	-0.270	-0.118	-0.194	0.015	0.000	-0.148
	2000kN	-1.963	-0.847	-0.506	0.037	-0.541	-0.235	-0.387	0.033	-0.003	-0.295
	3000kN	-2.957	-1.275	-0.756	0.055	-0.806	-0.353	-0.581	0.048	-0.005	-0.443
Curve pattern 1	1000kN	-0.976	-0.342	-0.250	-0.055	-0.188	-0.118	-0.120	-0.057	0.000	-0.094
	2000kN	-1.963	-0.684	-0.506	-0.117	-0.375	-0.235	-0.243	-0.113	-0.003	-0.187
	3000kN	-2.957	-1.029	-0.756	-0.178	-0.563	-0.353	-0.362	-0.173	-0.005	-0.283
Curve pattern 2	1000kN	-0.976	-0.342	-0.250	-0.055	-0.188	-0.118	-0.120	-0.057	0.000	-0.094
	2000kN	-1.963	-0.684	-0.506	-0.117	-0.375	-0.235	-0.243	-0.113	-0.003	-0.187
	3000kN	-2.957	-1.029	-0.756	-0.178	-0.563	-0.353	-0.362	-0.173	-0.005	-0.283

Table 2. Frequency varying proportion by initial stress method

	modality	V1	H1	V2	T1	Т2	V3	H2	Т3	L1	Н3
	prestress	Frequency variation (%)									
Linear pattern 1	1000kN	-0.005	-0.017	-0.041	-0.014	-0.267	-0.066	-0.009	-0.258	-0.005	-0.105
	2000kN	-0.011	-0.032	-0.089	-0.020	-0.533	-0.131	-0.022	-0.516	-0.013	-0.209
	3000kN	-0.016	-0.047	-0.137	-0.027	-0.800	-0.200	-0.031	-0.777	-0.020	-0.316
Linear pattern2	1000kN	-0.029	0.006	0.014	-0.027	0.101	0.021	-0.025	0.099	-0.013	0.037
	2000kN	-0.047	0.019	0.041	-0.047	0.208	0.055	-0.040	0.203	-0.018	0.085
	3000kN	-0.068	0.032	0.062	-0.068	0.314	0.090	-0.059	0.305	-0.025	0.133
Curve pattern 1	1000kN	-0.019	0.011	0.021	-0.014	0.231	-0.017	-0.012	0.015	-0.008	-0.039
	2000kN	-0.040	0.019	0.034	-0.027	0.456	-0.035	-0.022	0.026	-0.013	-0.081
	3000kN	-0.058	0.028	0.048	-0.047	0.670	-0.055	-0.034	0.035	-0.018	-0.122
Curve pattern 2	1000kN	-0.034	0.024	0.062	-0.020	0.664	0.024	-0.012	0.250	-0.005	0.004
	2000kN	-0.071	0.045	0.116	-0.047	1.311	0.045	-0.028	0.491	-0.010	0.009
	3000kN	-0.111	0.068	0.171	-0.067	1.939	0.066	-0.040	0.726	-0.018	0.011



equivalent prestressed force





Figure 3. Straight line pre-stressed steel bars' lay-out (mm)



Figure 4. Parabolic pre-stressed steel bars' lay-out (mm)



Figure 5. Frequency calculated by two methods