EXPERIMENTAL STUDIES OF DINAMIC CHARACTERISTICS OF MULTI-STOREY STEEL FRAME BUILDING LARGE-SCALE MODELS WITH DIFFERENT VERTICAL BRACINGS

by

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SYNOPSIS

The paper is devoted to experimental studies of space 9-storeyed models of steel carcass buildings of frame and frame-bracing systems 1/6 of natural size. The carcass models were tested for:free, forced (resonance) vibrations and static very intensive horizontal loads permitting to cause destruction of model constructions. The extent of the effect of vertical bracings, made in the form of metallic diagonal bracings and reinforced concrete panels on the changes of dynamic parametres was determined in steel carcass models at different schemes of arrangements of these bracings in the carcass frames. All together were tested 12 schemes of carcass buildings. Special attention was paid to variation of vibration frequencies and to the damping decrement of the models of steel carcasses when plastic deformations are developed in them.

At present in the seismic countries of the world tall structures with load-bearing frames become widely spread. Designing of such structures is related to the necessity of revealing and the analysis of specific features of their behaviour under the seismic conditions. Most reliable method of studies of arising problems is the experimental study of large scale models showing as much as possible structural peculiarities of real structures. In such a case it is possible to test experimentally and to make a comperative analysis of the behaviour of carcass buildings of different structural systems in elastic and elastic-plastic stages of their operation under the conditions of existence of dinamic forces like seismic ones. The estimation of the extent of antiseismic properties may be made on the basis of the analysis of certain determined experimentally periods, forms of vibrations and damping decrements, i.e. those things on which depend the formation and values of forces at an earthquake.

In this paper the results of experimental studies of large scale models of steel carcass buildings with frame and frame-bracing systems are given. The vertical bracings were

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made in the form of reinforced concrete panels and metallic diagonal bracings arranged according to different schemes in the carcass frames (Table 1,column 2). Models were 9-storeyed space two span carcasses with the scale 1:6, consisting of three transverse frames joined by longitudinal spanners. The total height of the model was 4.23m and plan dimensions were 2 x 1.74m. Columns had a box-shaped cross-section of two angles welded by a continuous seam along the whole height. In joints spanners were welded to columns along the external cross-section contour. Conventional carbon steel of the trade mark St.3 was used for the models. Reinforced concrete floor slabs 4cm thick were used. The model of frame-bracing carcass differed from the frame one by the existence of two types of vertical bracings, the latter were reinforced concrete panels 2cm thick reinforced with a network and metallic cross bracings. Reinforced concrete slabs were welded in eight points to the frame by means of placed in elements. Vertical bracings providing rigidity in the transverse direction were placed in the two extreme transverse frames.
A powerful vibromachine of inertial action was installed on the 9th floor of the model and was used as a source of forced vibrations. The frequency range and the power of the machine allowed to study the resonance regions of vibrations of the models till the element destruction. The models were also subjected to static horizontal loads applied on the levels of floors. The used complex method of dynamic and static studies permitted to determine most reliably the required characteristics of models of carcass buildings in the elastic and elastic-plastic stages of operation.

Tests of the models were carried out in the following sequence: free vibrations, static horizontal loads, forced vibrations (1 and 2 resonances) and again free vibrations.

Frequences and damping decrements of free and forced vibrations for the tested frame and frame-bracing systems of the models of steel carcasses with different arrangements of vertical steel and reinforced concrete bracings are given in Table 1.

According to the programme of tests, damages were caused by horizontal static loads in the model of frame carcass (Table 1, schemes of tests 1,2). Damages were cracks and openings of welded seams in the joints of transverse spanners and columns. The residual deformation on the level of the ninth floor was 18.6cm that is 1/25 of the model height. A heavily damaged model (Table 1, scheme 2) was subjected to further dynamic actions in the resonance regions I and II.The resonance frequency of tone 1 was decreased for 16% in comparison with the undamaged model. The experiment has shown that in spite of considerable damages, the carcass model preserved the ability to resist secondary large loads elastically and it showed high reliability of steel carcasses for antiseismic structures.

The tests of the second frame model (Table 1, scheme 4) with vertical bracings permitted to establish the extent of influence on frequency and damping decrement of vibrations. The tests of schemes of carcass models with steel bracings (Table 1,schemes 5,10) have been carried out in the elastic stage and the last schemes with reinforced concrete bracings were brought to destruction (Table 1, schemes 11,12). The test showed that steel cross bracings considerably increased the frame carcass rigidity, while reinforced concrete filling practically did not affect the rigidity of the frame system, since the accepted fixing construction of wall panels by means of welding of placed in elements to the carcass frames was found to be not effective. Reinforced concrete wall filling is heavily destroyed at forced vibrations in the regions of placed in elements arrangement due to the joined taking in of deformations with flexible steel constructions. Prefabricated wall panel new construction of vertical diaphragm plate is proposed. The main operating reinforcement is placed along the wall diagonals reaching four corners of the placed in elements fixed in the joints of the carcass. To prevent the wall falling out special elements are welded to the carcass frame.

It is seen from Table 1 that vertical steel bracings (Table 1, schemes 5,10) in the model of frame carcass (Table 1, scheme 4) considerably influence the change of the frequency of the fundamental tone vibrations, the frequency of tone 2 is negligibly affected. Most economic was the system of chess-board order of bracing arrangement (Table 1,scheme 7). Frequences of vibrations obtained at free vibrations (small stresses) are always higher than those obtained with resonance (calibrated stresses) tests. The coefficient characterizing the ratio $K=\frac{\omega_{FR.}}{\omega_{RES.}}$ is within 1.01 1.23 and its mean value does not exceed 1.1. Consequently, the stressed state within the certain limits did not result important influence on the frequency of vibrations of steel carcass models. The analysis of the values of damping decrements permits to conclude that their values depend, to a great extent, on the level of the stressed state. Damping decrements should be determined by structure tests with calculated loads. Damping decrements of models of steel carcasses determined with free vibrations are much smaller than resonance damping decrements, the value of the coefficient $K_1=\frac{\delta_{RES.}}{\delta_{FR.}}$ for the models of frame carcasses is 1.34 3.75 for the models of frame-bracing carcasses with steel bracings it is 5.85 10.8.

At the development of plastic deformations in the model of a frame carcass the damping decrement determined at the resonance was 2.5 times greater than for the undamaged model.

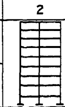
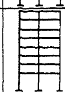
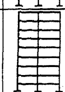
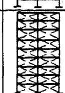
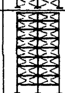
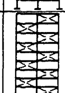
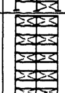
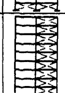
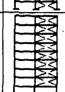
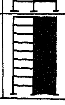
Reinforced concrete filling in the frame-bracing carcass model not feeling horizontal loads, influences considerably the increase of the dissipative ability of the system.

Vertical steel bracings increase the value of the damping decrement in an average for 1.5 times and reinforced panels increased the decrement almost twice.

The carried out tests have shown that in symmetric by their plan models of steel carcasses, the torsional resonance may be formed due to the action of symmetrically applied dynamic forces. This torsional resonance after the passage of the resonance of tone 1 of coming frequencies, the frequency of the torsional resonance is higher for 1.2 times than that of tone 1.

TABLE 1

FREQUENCES AND DAMPING DECREMENTS OF THE MODELS OF STEEL CARCASSES OBTAINED WITH FREE AND RESONANCE VIBRATIONS

NN TEST SCHEMES	SCHEME OF CARCASS	FREQUENCY OF VIBRATIONS, Hz.					DAMPING DECREMENT			NOTES
		FREE VIBRATIONS	RESONANCE VIBRATIONS			$K=\frac{\omega_{FR}}{\omega_1}$	FREE VIBRATIONS	RESONANCE VIBRATIONS	$K_1=\frac{\delta_{RES}}{\delta_{FR}}$	
		$\omega_{FR.}$	1 TONE ω_1	2 TONE ω_2	TORSIONAL $\omega_{TOR.}$		$\delta_{FR.}$	$\delta_{RES.}$		
I	2	3	4	5	6	7	8	9	IO	II
I		2,59	2,54	7,I	3,I	I,04	0,08	0,I07	I,34	BEFORE DAMAGING
2		2,3I	2,I3	5,9		I,08	0,I06	0,27	2,54	AFTER DAMAGING
3		I,98	I,82	5,0		I,09	0,I4	0,2I2	I,5I	WITH DAMAGES
4		2,68	2,66	8,7	3,23	I,0I	0,04	0,I5	3,75	
5		5,2I	5,0		5,5	I,04	0,027	0,227	8,4	
6		5,0	4,06		5,0	I,23	0,0I9	0,I97	I0,4	
7		4,4	3,75		4,55	I,I7	0,023	0,25	I0,8	
8		3,54	3,45	I0,0		I,03	0,027	0,I58	5,85	
9		4,06	3,55	I0,0		I,I4	0,024	0,258	I0,74	
I0		3,48	3,I8	9,0I		I,09	0,024	0,225	9,38	
II		2,84	2,8			I,0I	0,09I	0,2I	2,3I	
I2		2,78	2,63	8,0	2,86	I,06	0,II	0,29	2,64	BEFORE DAMAGES
		2,55	2,48	6,76	3,I2	I,03	0,07	0,258	3,69	AFTER DAMAGES