DESTRUCTIVE AND NON—DESTRUCTIVE TESTS OF FRAMED LIGHT—WEIGHT PANEL BUILDINGS

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SUMMARY

The main test results for earthquake resistance of framed light—weight panel buildings; such as dynamic characteristics of these buildings in eight cities of China and results of pseudo—static non—destructive simulation test of such 5—story building and destructive test of two prototype buildings are briefly introduced. Based on the test results; a reasonable schematic diagram for calculation and a computing method of this kind of structures are proposed at last.

INTRODUCTION

A new building system, called light—weight panel framed building, has been developed in recent years in China. The main load—bearing structure of the system is a precast reinforced concrete frame and its interior and exterior walls are made of different kinds of light —weight panels, therefore the main features of the new system are: light in own weight, good in earthquake resistance, high efficiency and short time in construction.

The structural systems of the light—weight panel framed buildings can be divided into two basic systems:

(1) Slab—column system which consists of square hollow columns and ribbed slabs.

(2) Beam—slab—column system which consists of precast beams, slabs and square hollow columns.

Slab—column—shear wall structual system or slab—column—brace structural system and so on can be formed by adding some shear walls, shafts or braces in the above basic systems.

Several hundred groups of various types of structural elements and joints, and some prototype buildings and main structures of the new building system have been experimentally investigated in laboratory or in sites in recent years in China. The test results of the structural system made by the author are briefly introduced in this paper.

TESTS OF DYNAMIC CHARACTERISTICS OF PROTOTYPE FRAMED BUILDINGS

The tests were made recently in eight cities of China. The structural characteristics and test results of part of buildings are listed in Tab.1.

The test building is a 5—story apartment with 12 panels on each floor (Fig.1), its main structnre is a precast R.C. frame which consists of ribbed slabs of dimension 3300×4800mm and square hollow columns of dimension 350×350mm (internal diameter in 200mm). SW1 shown in Fig.1 is reinforced conerete brace, SW2 and SW3 are ribbed reinforced concrete slabs.

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Dynamic Characteristics

The fundamental period in transverse direction measured by ambient method is the same as that measured by initial displacement——pull and release method, and it is equal to 0.29 sec., the measured damping ratio of the test structure ξ is equal to 0.038.

In—Plane Characteristics of Floor Slabs

When a concentrated load of 6 tons was applied at the middle of the top floor, the measured displacements of the tops of columns are shown in Fig 2. It is evident that the diplacements vary around the average value 0.321mm ., the lataral stiffness is found as 18.7 tons/mm.

The displacements of the tops of the columns under the action of a concentrated of 6 tons which was applied at the top of column 4 lie in a straight line with a slope as shown in Fig.3, its regression equation is found as

$$Y = 0.611 - 0.0453X$$

where $X = 0, 1, 2, \cdots, 12$.

This equation shows that displacement at the top of any column consists of two parts: displacement at the middle of the top floor which is equal to 0.339mm., (close to the average value, 0.321mm., when a concentrated load of 6 tons was applied at the middle of the top floor), and the torsional displacement caused by the rotation of the top floor about its center with an angle of rotation $\theta = 2.8''$, the torsional stiffness is found to be 8.648×10^{6} ton • m/rad. The test results mentioned above show that the in—plan stiffness of floor slabs is quite satisfactory.

DESTRUCTIVE TEST OF A 3—STORY OPEN FRAME

Brief Description of the Test Structure

The test structure is a 3—story precast reinforced concrete open framed structure with 5 panels and two bays but without panel walls, the spacing of columns is 3.2m, the span of the frame is 4.5m, and the story height is 2.8m. The elementary structural elements are square hollow columns(300 × 300mm) with 4 ϕ14 reinforcing bars and ribbed slabs(3200 × 4500mm.) with edge beams, each of which has 1 ϕ16 reinforcement in the tension zone and 1 ϕ12 reinforcememt in the compression zone.

In—Plan Characterisitcs of Floor Slabs

The measured displacements at the top of columms when a concentrated load of 4 tons was applied at the middle of the top floor are shown in Fig. 4. The figure shows that the displacements vary around the average value 1.385mm with a little torsion, the lateral stiffness is found to be 2.89 tons/mm.

The displacements at the top of all columns are essentially equal when two concentrated loads acted at the tops of columns 2 and 5 or two triangular distributed loads acted on columns 2 and 5 (Fig. 5), even though the triangular distributed loads are increased to 66 tons(ultimate load), the displacements are still very close to each other (Fig. 6).

The displacements at the top of columns under the action of two equal concentrated loads but opposite in direction applied at the top of columns 2 and 5, are shown in Fig. 7. The figure shows that the displacements lie in an inclined straight line with a slope, the torsion stiffness is found to be 758.9 ton.m/rad.

No sliding along the joint of floor slabs occurs when the concentrated load $\sum P_i$ with a triangular distribution does not exceed 30 tons. The max. offset of the floor slabs on the first, second and third story are 0.14, 0.10 and 0.03mm respectively when $\sum P_i = 42$ tons and 0.40, 0.49 and 0.99 mm respectively when $\sum P_i = 66$ tons.

The test results mentioned above show that the integrity of floor slabs is satistactory, the in—plane stiffness of floor slabs is very large.

Dynamic Characteristics

The dynamic characteristics measured by ambient, initial displacement—pull and release, initial velocity—rockets and resonance methods are listed in Tab. 2. It can be seen from Tab. 2 that:

(1) The dynamic charecteristics measured by all methods mentioned above are approximately equal.

(2) The frequency measured during the application of live loads and wall weights is decreased by about 20% as compared with the frequency of the open frame.

(3) The frequencies measured during the ranges of post—loads $\sum P_i = 30$, 42, 66 tons are decreased successively.

Ductility

Based on the hysteresis loop of measured load—(top) displacement and the development of strains and cracks, the initial yield load of the test structue is found to be 42 tons, and the corresponding initial yield displacement is 2.10 cm. Since the max. displacement is equal to 11.3 cm during the second cycle of loading (66 tons), corresponding ductility is found to be 5.38.

The ductility mentioned above was measured when thrust was applied and the ductility was 11.69 when the same load was applied in opposite direction.

In fact, the test structure did not collapse when the top displacement exceeded 1 m, this fact shows that the ductility of the test structure is quite satisfactory, and the ultimate displacement is very large.

The ultimate load and collapse load are 66 tons aud 60 tons respectively.

DESTRUCTIVE TEST OF A 5—STORY PROTOTYPE BUILDING

Brief Description of the Test Building

The plan and the main structure of the test building is the same as the 3—story open frame mentioned above only number of stories changes, and it has interior and exterior panels also. The transverse end panels are embedded in the columns of the frame, while the longitudinal panels are placed to enclose the main structure. All exterior panels are precast R. C. ribbed slabs. There are two types of interior panels, hollow gypsum panels and air entrained concrete block masonry.

Static and dynamic tests were carried out successively for four kinds of structure: (1) open framed stucrute; (2) open framed structure with tarnsverse end panels; (3) open framed structure with exterior panels only (including transverse end panels and longitudinal exterior panels); (4) open framed structure with exterior and interior panels and seventy percent of live loads.

Stiffness of the Whole Structure

The measured average stiffness of each kind of structure under the action of two traingular distributed loads on columns 2 and 5 is listed in Tab.3. It can be seen from Tab.3 that the effect of interior and exterior panels on the stiffness of the whole structure is significant. As compared with the stiffness of the open frame; the following conclusions will be obtained:

(1) Structural stiffness due to transverse end panels will increase as many as 1.85 times.

(2) Longitudinal panels have little effect on the stiffness in transverse direction.

(3) Structural stiffness due to interior panels will increase as many as 1.24 times.

Dynamic Characteristics

The measured natural frequencies and damping Characteristics of the test structure are shown in Tab.4. It can be seen from Tab.4 that:

(1) The damping of the open frame is the minimum value among the other structures, and the damping of the frame with panels increases significantly.

(2) Natural frequency of the test structure due to transverse end panels increases about 53% as compared to the open frame.

(3) Natural frequency in the longitudinal direction of the test structure due to longitudinal panels increases 83%.

(4) Natural frequency in the transverse direction of the test structure due to interior panels increases only a little, but the mass of the test structure in this case increases significantly. This fact shows that the effect of interior panels on the structural stiffness is significant, and it is consistent with the static test results.

Deformation and Failure Characteristics of the Test Structure

In order to keep the test building to be usable without repair or with a little repair after the test, the highest test load is controlled to be 98 tons. The top displacement of the test structure under the highest load was 2.3cm, it is only 0.16% of the total height of the test structure. In this case, no damage to the main structure was found, only some cross cracks occurred on the interior panels. But, some gypsum strip panels suffered serious damage.

The highest test load is about four times as large as the seismic load specified in the Chinese Aseismic Code, this fact shows that the test structure will be safe in an earthquake of intensity Ⅶ.

ANALYSIS AND CONCLUSIONS

It can be concluded from the test results mentioned above that:

(1) The connections of elements of the main structure of the light—weight panel framed building are reliable, and its integrity are quite satisfactory.

(2) The in—plane stiffness of floor slabs is very large, and can be assumed as infinite for simplification.

(3) Floor slabs can be treated as flange of beams. Based on the test results and

according to the principle of equivalent strain, the effective flange width of ribbed slabs can be found as one third of the span length. The natural frequencies computed by the assumed stiffness of the frame are listed in Tab.2 or Tab.4. It can be seen from these tables that computed values approach to measured values.

(4) Displacements of the test structure are mainly caused by shear deformations. The fundamental period can be computed by the following formula:

$$T = 1.5H\sqrt{\frac{q}{k}}$$

in which H, q, K are the total height, the average weight per unit length along the height and the average shear stiffness of the whole structural unit respectively. K can be expressed as

$$K = K_f + K_s + K_r$$

in which K_f, K_s and K_r are average shear stiffness of the total frame, all shear walls and all braces of the whole structural unit respectively.

when the torsional frequencies of free vibration of a building are computed, K, q are the torsional stiffness and the product of rotatory inertia and acceleration of gravity respectively.

The computed results show that the approximation method gives satisfactory results (see Tab.2).

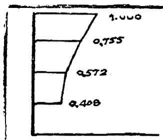
(5) Results of two destructive tests and elasto—plastic analysis show that the earthquake resistance of the test structure is satisfactory, and it will be safe in an earthquake of specified design intensity.

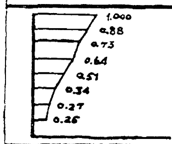
The mensured values of natural periods and mode shapes. Tab.4

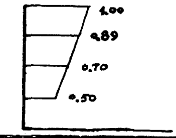
Me	It	1st tran. freq.				1st longi. freq.			2nd trans. freq.	1st tor. freq.		
		I	II	III	IV	II	III	IV	I	I	II	IV
M1	F	2.33	3.27	2.85	3.07	1.95	3.57	3.45				
M2	F	1.82	3.23	2.19					6		3.06	
	D											
M3	F	2.08	3.22	2.50	2.75							
	D	2.2	3.79	3.82	4.1							
M4	F	1.82	2.50		2.53				5.32	1.93	2.9	3.44
	D											
C	A	1.67	2.47	1.95	2.46							
	B											

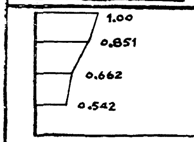
Note:Symbols in Tab.4 are same as those in Tab.2

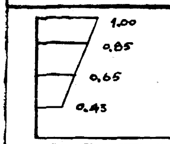
Measured values of natural periods and mode shapes Tab. 1

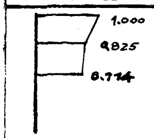
<table>
<tr><th>No</th><th>N</th><th>Structural system</th><th>Type of external wall</th><th>Type of internal wall</th><th>Fundamental period(sec.) and transverse mode shape</th></tr>
<tr><td>1</td><td>5</td><td>beam—slab—column</td><td>asbestos cement panels</td><td>gypsum panels</td><td>

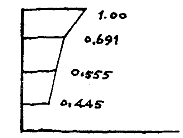
$T_t = 0.265$
$T_l = 0.284$</td></tr>
<tr><td>2</td><td>8</td><td>beam—slab—column</td><td>reinforced concrete panels</td><td>air entrained concrete blocks and gypsum panels</td><td>

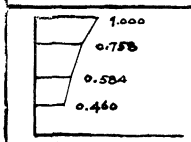
$T_t = 0.582$
$T_l = 0.382$</td></tr>
<tr><td>3</td><td>5</td><td>beam—slab—tube wall</td><td>air—entraining concrete panels</td><td>gypsum panels</td><td>

$T_t = 0.285$
$T_l = 0.280$</td></tr>
<tr><td>4</td><td>5</td><td>slab—column—shear wall</td><td>ribbed panels</td><td>gypsum panels with wall paper</td><td>

$T_t = 0.281$
$T_l = 0.264$</td></tr>
<tr><td>5</td><td>5</td><td>slab—column—shear wall—brace</td><td>ribbed panels</td><td>gypsum panels</td><td>

$T_t = 0.290$</td></tr>
<tr><td>6</td><td>5</td><td>beam—slab—column—shear wall</td><td>asbestos cement—air—entraining concrete panels</td><td>gypsum panels</td><td>

$T_t = 0.299$
$T_l = 0.264$</td></tr>
<tr><td>7</td><td>5</td><td>slab—column—steel brace</td><td>aluminum alloy panels</td><td>gypsum panels with wall paper</td><td>

$T_t = 0.25$
$T_l = 0.30$</td></tr>
<tr><td>8</td><td>5</td><td>slab—column—shear wall</td><td>aluminum alloy panels</td><td>gypsum panels with wall paper</td><td>

$T_t = 0.255$
$T_l = 0.251$</td></tr>
</table>

Note: T_t —— Fundamental period in transverse direction; T_l —— Fundamental period in longitudinal direction; No —— No. of building; N——Number of stories.

The measured values of average stiffness Tab. 3

Kind of structure	I	II	III	IV
Average sitffness ton/cm	17.61	48.32	49.91	71.91

Table 2

Me	It	1st Translation fraq.					2nd Trans. fraq.			3rd	1st Torsional fraq.					2nd Tors
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(5)	(1)	(1)	(2)	(3)	(4)	(5)	(5)
M1	F	3.40	2.81	2.74	2.51	2.00										
M2	F	3.39	2.75			1.99	10.0	8.66	6.57	20.83	3.83	3.20	3.04	2.70	2.29	
	D	1.20	1.46			2.46	2.57	2.14	2.43		1.30	1.58	2.11	2.12	2.54	
M3	F	3.35	2.74	2.65	2.18	1.70										
	D	1.20	1.32	1.89	3.40	3.63										
M4	F					1.65			5.45						1.90	6.60
	D					3.81			2.89						3.35	2.12
C	A		2.32					7.69				2.81				
	B		2.50					8.10								

Notes: (1)-Opan frame; (2)-Live loads and wall weights have been applied; (3)-post-loads $\sum p_i=30$tons; (4)-Post-loads $\sum p_i=42$ tons; (5)-Post-londs $\sum p_i=66$tons; Me-Method; M1-Ambient; M2-Initial velocity-rockets; M3-Initial displacement; M4-Resonance testing; F-Frequency; D-Damping ratio; C-Computed value; A-Values computed by the exact method; B-Values computed by the approximation formula; It-Measured items.

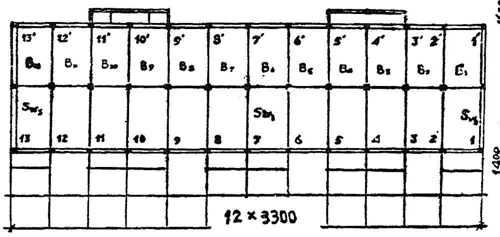


FIGURE 1

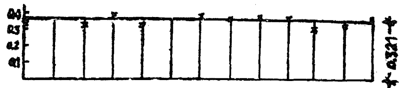


FIGURE 2.

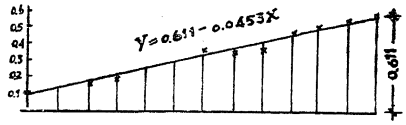


FIGURE 3.

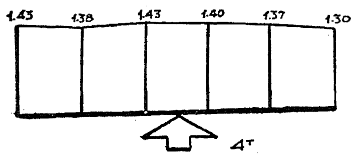


FIGURE 4.

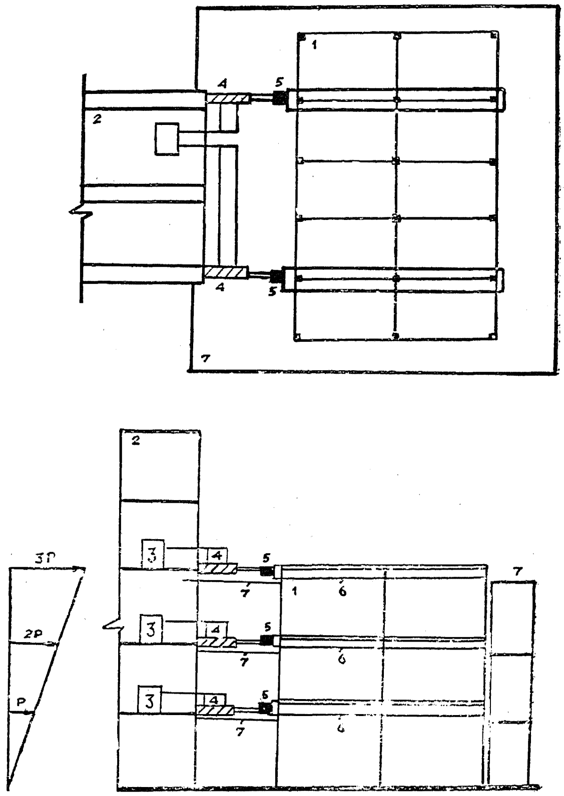


FIGURE 5.

1. Test structure; 2. A braced building with sheer walls;
3. Oil pump; 4. Oil jack;
5. Pressure transducer; 6. Pull bar; 7. Working scafford.

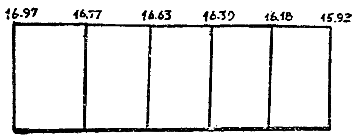


FIGURE 6.

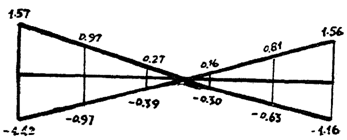


FIGURE 7.