EARTHQUAKE RESPONSE OF REINFORCED CONCRETE FRAME-CRACKED SHEAR WALL SYSTEMS

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The paper presents a summary of the research on the quantitative definition of the changes in the vibrational and structural characteristics of reinforced concrete frame-reinforced concrete shear wall systems, with cracked and uncracked shear walls. It is observed that regardless of the extent of the damage, not all key characteristics vary the same amount, some properties could even be assumed to remain relatively unchanged as far as engineering computations are concerned.

INTRODUCTION

One of the most efficient ways of providing lateral stiffness to high rise frames is the employment of reinforced concrete shear wall. The research have indicated that depending upon the slenderness of a given frame there exist practical limits for the shear wall, beyond which further increases in dimensions will not sufficiently increase the lateral stiffness (Refs. 2,6,7). The field observations have also indicated that since the shear wall is the stiffest component in frame-shear wall combination, it will draw a larger share of the seismic forces, thereby making it more susceptible to damage, i.e. cracking (Refs. 2,7). Research on the identification of the optimal shear wall-frame arrangements and shear wall dimensions, seismic response characteristics of these structural systems, and the interaction and seismic response characteristics of the structural systems with damaged shear walls have been completed (Ref. 2). This paper presents the results pertaining to the changes in the vibrational and seismic characteristics of the reinforced concrete frame-reinforced concrete shear wall systems with cracked and uncracked shear walls.

The engineering decisions are based on quantitative analyses of undamaged structures and qualitative estimates for the extent of the damage and its possible influence on a given structure. This paper attempts to provide the numerical benchmarks for the effects of structural deterioration due to an earthquake on the changes in the vibrational characteristics. The results could also be employed in the evaluation of the structural integrity of earthquake damaged structural systems.

STRUCTURAL SYSTEMS AND ANALYSIS

The investigation employed two basic reinforced concrete frames, referred to herein as Frame-1 and Frame-2. Frame-1 is a three bay (7.6 m + 9.15 m + 7.6 m), ten story (4.8 m + 9 @ 3.6 m) frame with bent spacing of 8.2 m. The frame was designed in accordance with the provisions of Ref. 5, and previous editions, as described in Ref. 4 and summarized in

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Ref. 2. Frame-2 is a three bay (6 m + 6 m + 6 m), ten story (4.5 m + 19 @ 3.6 m) frame with bent spacing of 7.5 m. The frame was designed in accordance with the provisions of Ref. 1, described in Ref. 8 and summarized in Ref. 2. The lateral rigidity of both frames was provided by the moment resistant connections employed in the construction.

In arriving at the frame-shear wall systems two different configurations were used. In Type-A interior columns and the beams of the interior bay were removed, and a shear wall was placed at the center bay. In Type-B, the rightmost columns were removed and a shear wall was attached to the beams. This combination has resulted in a quasi-four bay structure. It should be noted that by varying the length of the shear wall the overall length of the structural system was varied as well. The effects of the different types of shear wall attachments and the variation of the wall length could be best noted through the following example: for Frame-1 with Type-A arrangement out-to-out dimensions vary from 17.64 m to 20.08 m, whereas for Type-B arrangement these dimensions will be 26.79 m and 29.23 m. Through this wide variation of the dimensions, it is possible to draw general conclusions that can be applicable to similar structures of different dimensions.

The cracking in the shear walls was assumed to have taken place at each floor level with equal intensity. It was assumed that the cracking was X-shaped, i.e. two diagonal cracks extending from lower left to upper right and from lower right to upper left corners of the portion of the shear wall defined by two consecutive beams and the vertical extremities of the shear wall (Ref. 2). The cracks were assumed to be severe enough to have full separation between the crack surfaces, but to hold together with the reinforcement placed in the wall. The structural analysis was conducted by using finite element method (Ref. 3). Both static and dynamic analyses were conducted for various phases of the research. The definition of seismic loads, for the portion reported herein, has employed routine engineering assumptions (Ref. 5).

RESULTS

Highlights of the findings are numerically presented in Table 1. Inspection of the table indicates that regardless of the extent of the damage, the change in the fundamental frequencies is small, with the tendency of increase as the walls get stiffer. Similarly, as the wall dimensions increase the differences between the fundamental frequency of vibration for wall arrangements Type-A and -B get smaller. The changes in the horizontal deflection of the top of the buildings, which can be used as a measure of lateral stiffness, are far greater than the changes in the fundamental frequencies for structural systems having cracked and uncracked walls. Interestingly enough, the portion of the base shear carried by the shear wall is relatively insensitive to the cracking, or lack thereof. From inspection of the Table it can be concluded that for relatively flexible shear walls, the cracking does not have a noticeable effect on the structural and vibrational characteristics of the system. As the relative lateral stiffness of the wall to the total structure increases the differences become more discernible. For all practical purposes, the changes in the fundamental frequency of vibration are very small. Thus, unless the structure is a very critical one, in the assessment of the post-earthquake characteristic of the given structure, the values used for the pre-earthquake values could be employed. It should also be noted that the major change in the structural characteristics is the noticeable reduction of the lateral stiffness of the structural system.

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TABLE 1: STRUCTURAL AND VIBRATIONAL CHARACTERISTICS OF THE FRAME-SHEAR WALL SYSTEMS

		Frequencies (Hz)			Top Deflection (mm)			% Base Shear Carried by S.W.	
Type	SW Length (m)	Uncracked	Cracked	% Change	Uncracked	Cracked	% Change	Uncracked	Cracked
1-A	2.44	0.44	0.44	0.1	41	41	0.+	75.3	75.2
(t_w =	3.05	0.48	0.47	1.8	34	35	2.8	82.9	82.8
0.3m)	3.66	0.53	0.50	4.8	28	30	8.5	87.4	87.2
	4.27	0.58	0.53	8.8	22	26	14.1	90.6	90.
	4.88	0.64	0.56	13.6	18	23	27.3	92.2	91.6
1-B	2.44	0.55	0.55	0.	17	17	0.+	51.8	51.7
	3.05	0.57	0.56	0.9	16	16	1.1	62.4	62.3
	3.66	0.60	0.58	2.6	14	15	4.0	69.9	68.9
	4.27	0.63	0.60	5.1	13	14	8.8	75.4	73.4
	4.88	0.66	0.61	8.4	11	13	15.3	79.3	76.7
2-A	3.66	0.23	0.23	4.2	196	210	7.2	91.2	91.1
(t_w =	4.27	0.25	0.23	7.5	164	186	14.	93.2	93.
0.41m)	4.88	0.27	0.24	11.4	136	165	21.7	94.5	94.
	5.49	0.29	0.25	15.5	113	147	30.9	95.5	94.8
	6.10	0.32	0.26	19.8	93	132	40.8	96.2	95.4
2-B	3.66	0.28	0.27	2.4	100	103	3.5	78.3	77.7
	4.27	0.29	0.27	4.5	91	98	7.2	82.4	81.2
	4.88	0.30	0.28	7.1	83	93	12.3	85.4	83.7
	5.49	0.31	0.28	10.2	74	88	18.6	87.7	85.6
	6.10	0.33	0.29	13.6	66	83	26.	89.4	87.1