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ENERGY ASPECTS OF COMPOSITE / HYBRID FRAMES

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ABSTRACT

In spite of growing need and use of composite and hybrid structures, very little is known at present regarding their behavior under lateral static and dynamic forces. The appearance of the hybrid construction is as a result of pursuing the economy and high-efficiency of the construction, but some problems are involved in structural design.

In this study, static and non-linear dynamic analyses of the three rigid composite model frames without shear walls or bracing with three, six, and nine stories are carried out by using the non-linear dynamic analysis program DRAIN-2DX. Fiber beam-column element is used to model steel-concrete beams and columns. Six-story frame is selected as the standard number of stories. Three-story and nine-story frames are selected for comparison. The scope of the paper includes:

1) Predicting the reduction factor R_w.
2) Input energy and hysteretic energy demand on low-rise composite structures.

KEYWORDS

Seismic input energy; composite frames; reduction factor R_w

INTRODUCTION

There has been a growing need and use of composite and hybrid structures in recent years, but very little is known at present regarding their behavior under lateral static and dynamic forces. The appearance of the hybrid construction is as a result of pursuing the economy and high-efficiency of the construction, but some problems are involved in structural design. For instance, what is the reduction factor R_w? Current codes are of little help and design and analysis work is primarily based on intuition of the engineers.

The main issues for improving the earthquake-resistant design (EQ-RD) of new structures and the proper upgrading of existing hazardous facilities can be grouped under the following three elements; earthquake input, demands on the structure, and supplied capacities of the structure. Since damage involves non-linear response, the only way to estimate damage and the actual behavior of a facility under severe EQ excitation is to consider its inelastic behavior (Akbas et al., 1995; Shen et al., 1994; Sivakumaran et al., 1991; Theeravat et al., 1996). One of the most reliable ways to define the damage potential of an EQ ground shaking is to compute its energy input.

In this study, static and non-linear dynamic analyses of the three rigid composite model frames without shear walls or bracing with three, six, and nine stories are carried out by using the dynamic analysis program DRAIN-2DX (Prakash, et al. 1993). Six-story frame is selected as the standard number of stories. Three-story and nine-story frames are selected for comparison. The scope of the paper includes:

1) Reduction factor R_w.
2) Input energy and hysteretic energy demand on low-rise composite structures.

SEISMIC DESIGN OF FRAMES

Three rigid composite model frames with three, six, and nine stories are designed for this investigation (Figs. 1 and 2). All frames are designed in accordance with the 1994 Uniform Building Code and 1994 AISC Manual. The structures have two exterior frames and 5 interior frames. All interior frames are assumed to be pinned connected and used for gravity loads only except the middle frames, that are the analyzed composite frames. The composite frames are made of A572Grade50 structural steel and 3500 psi of concrete. The elements used for beams and columns are summarized in Table 1. The structures are designed for a live load of 50 psf and dead load of 100 psf. The load combinations of (1.2D.L. + 1.6L.L.) and (1.2D.L. +0.5L.L. + 1.5E) are used for all members. The structures are assumed to be in seismic zone 4. In designing the frames, reduction factor R_w is taken as 6 for this study.

SEISMIC ANALYSIS OF THE FRAMES

The two-dimensional model of frames were built for non-linear time history analysis using a general purpose inelastic dynamic analysis program, DRAIN-2DX (Prakash et al., 1993). Fiber beam-column elements were used to model steel-concrete beams and columns. Inelastic beam elements were used in each span of girders. P-M interaction relation, suggested by LRFD, was used as yielding surface of column elements. 5% of strain hardening was assumed for the post-yielding stiffness of steel beams and columns. P-Δ analysis was not considered in the analysis. The structures were subjected to three representative earthquakes, El Centro, Taft, and Northrigde (Newhall Station) and all earthquakes records were factored to 0.3g and 0.5g, respectively. The properties of the earthquakes are given in Table II. A step-by-step time integration with constant acceleration assumption was used in the dynamic analysis. Mass was lumped at joints, and 2% viscous damping was included.

RESULTS

Results from non-linear time history analysis are presented in the form of energy input, V/W vs. Δ, and strain level diagrams in Figs. 3,4, and 5.

Energy Input

Energy inputs for all frames are shown in Fig. 3. Northrigde (Newhall Station) is the most severe one among the three earthquakes in terms of energy dissipated by structural members (hystretic energy). For the 3-story frame, hysteretic energy is very close to the damping energy for El Centro and Taft. For the 9-story frame, damping energy is 2-3 times bigger than hysteretic energy. Damping energies are very close to each other

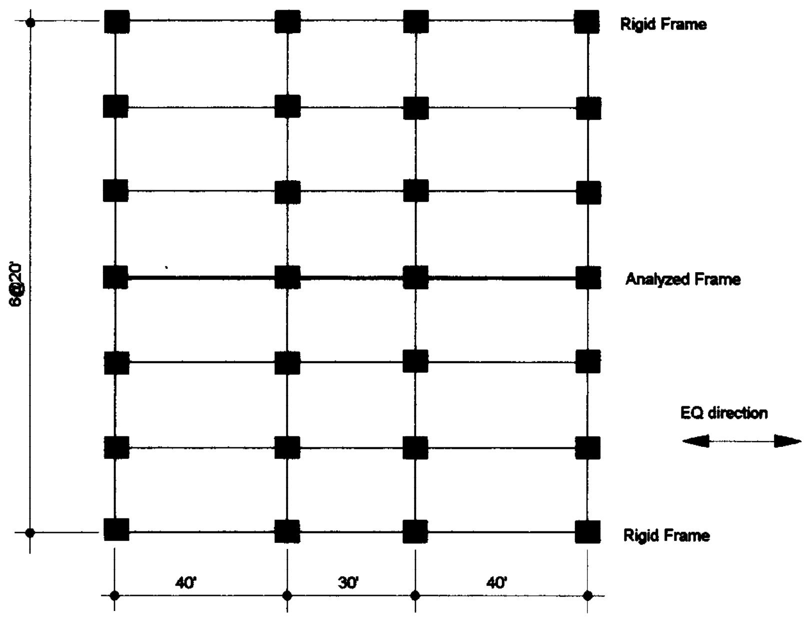


Figure 1. Plan of the structures

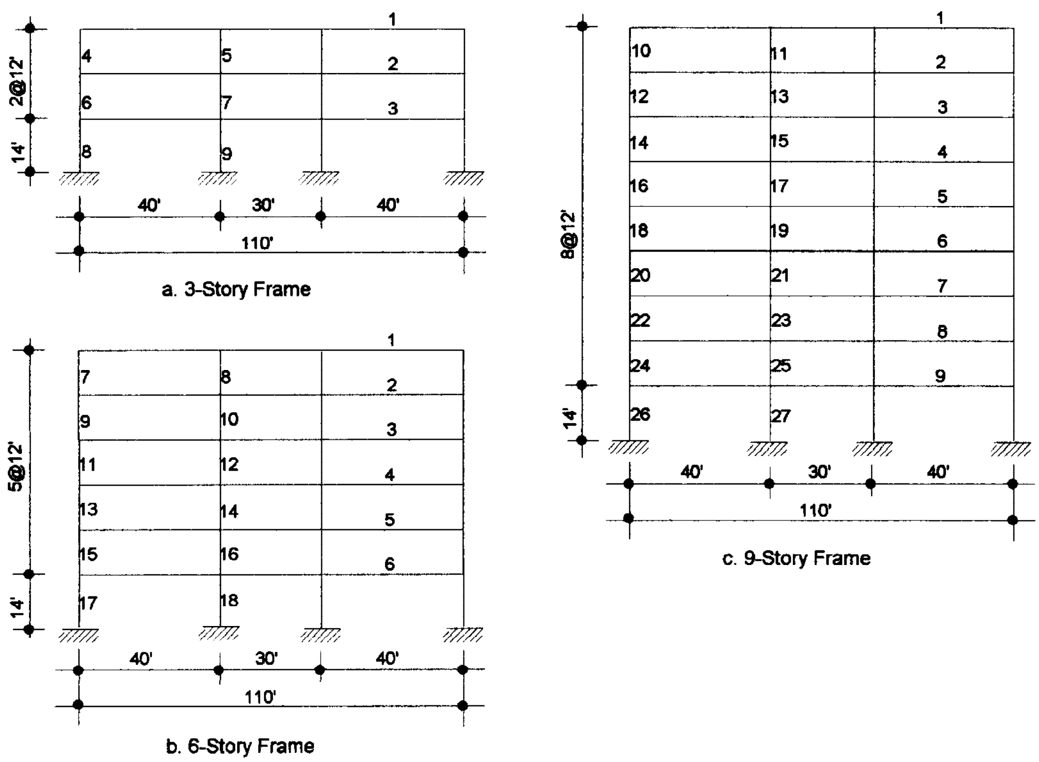


Figure 2. Elevation of the frames

Table I. Elements and member sizes of the frames

Type	Cross Section (in/in)	W-Shape	No. of Reinf. bars
1	---	W24x84	---
2	---	W30x124	---
3	---	W30x124	---
4	18/18	W10x112	4-#8
5	18/18	W10x112	4-#8
6	20/20	W14x109	4-#10
7	20/20	W14x109	4-#10
8	20/20	W14x109	4-#10
9	20/20	W14x109	4-#10

a. Details of the 3-Story Frame

Type	Cross Section (in/in)	W-Shape	No. of Reinf. bars
1	---	W24x76	---
2	---	W33x152	---
3	---	W33x152	---
4	---	W33x152	---
5	---	W33x152	---
6	---	W33x152	---
7	18/18	W10x77	4-#8
8	20/20	W12x106	4-#9
9	18/18	W10x77	4-#8
10	20/20	W12x106	4-#9
11	20/20	W12x106	4-#9
12	24/24	W14x145	4-#10
13	20/20	W12x106	4-#9
14	24/24	W14x145	4-#10
15	20/20	W12x120	4-#9
16	24/24	W14x233	4-#11
17	20/20	W12/120	4-#9
18	24/24	W14x233	4-#11

b. Details of the 6-story frame

Type	Cross Section (in/in)	W-Shape	No. of Reinf. bars
1	---	W24x76	---
2	---	W33x118	---
3	---	W33x118	---
4	---	W36x160	---
5	---	W36x160	---
6	---	W36x160	---
7	---	W36x160	---
8	---	W36x160	---
9	---	W36x160	---
10	18/18	W10x77	4-#8
11	18/18	W10x77	4-#8
12	18/18	W10x112	4-#8
13	20/20	W12x120	4-#9
14	18/18	W10x112	4-#8
15	20/20	W12x120	4-#9
16	20/20	W10x106	4-#9
17	24/24	W14/145	4-#10
18	20/20	W12x106	4-#9
19	24/24	W14x145	4-#10
20	20/20	W1x120	4-#9
21	24/24	W14x193	4-#11
22	20/20	W12x120	4-#9
23	24/24	W14x193	4-#11
24	24/24	W14x233	4-#11
25	24/24	W14x283	4-#11
26	24/24	W14x233	4-#11
27	24/24	W14x283	4-#11

c. Details of the 9-Story Frame

Table II. Ground motion components and their properties

Site	Date	Location	Compon.	Max. Acc. ($m/sec.^2$)	Magnitude
Imperial Valley	1940	El Centro	S00E	0.3483g	7.0
Kern County	1952	Taft	S69E	0.1793g	5.9
Northridge	1994	Newhall	---	0.63g	6.4

for three frames when structures are subjected to 0.5g of the three earthquakes. In case of 0.3g, damping energies differ from each other for each of the earthquakes.

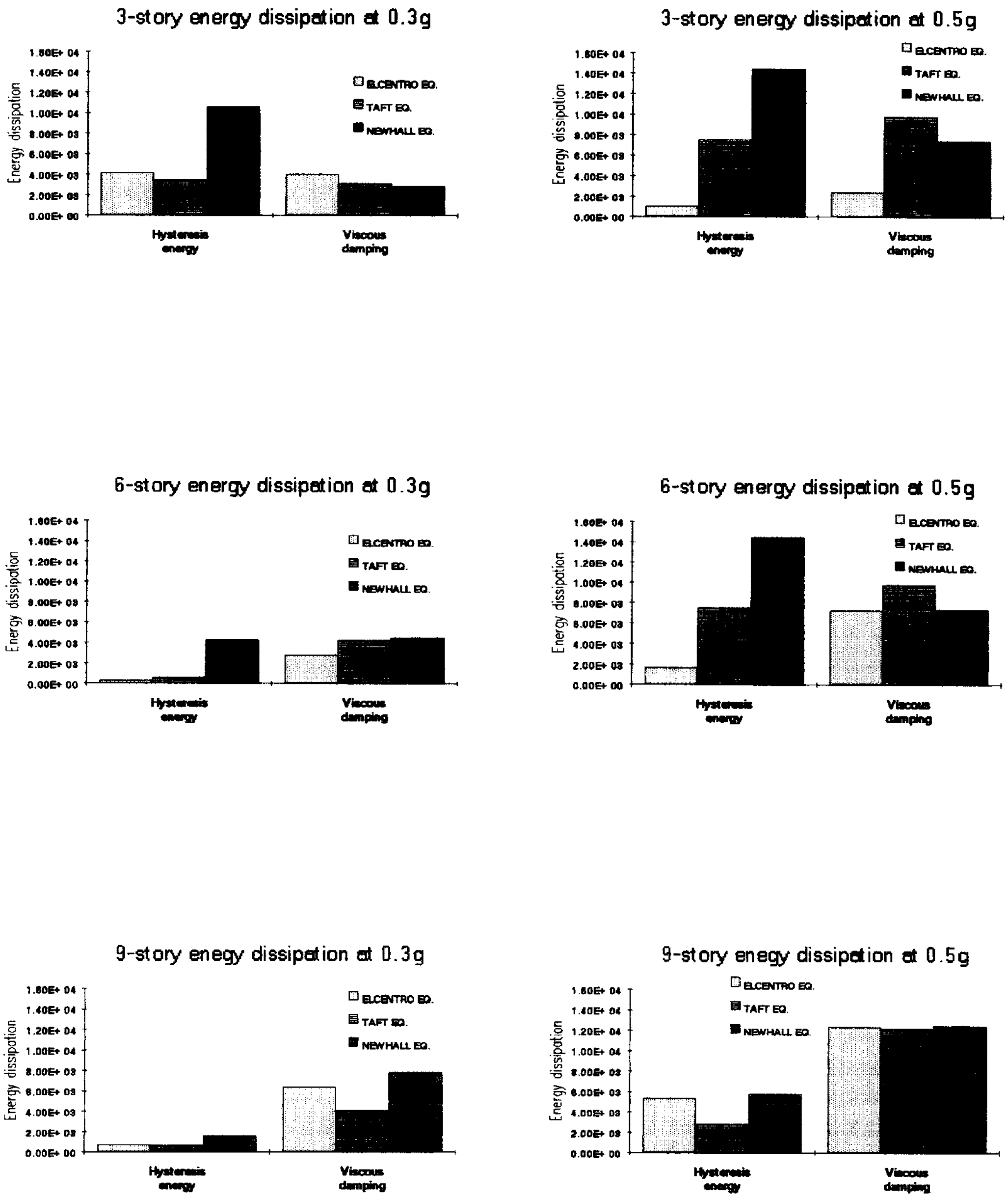
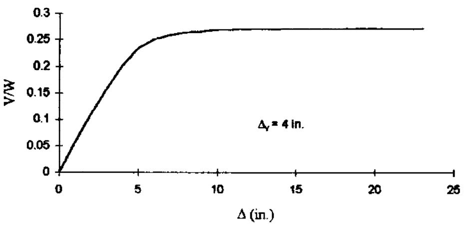


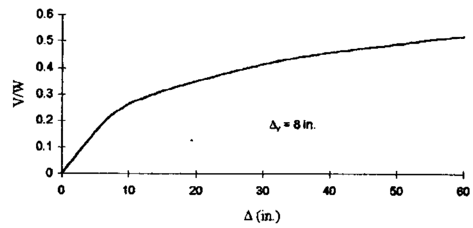
Figure 3. Energy inputs for the frames

V/W vs. Δ Diagrams

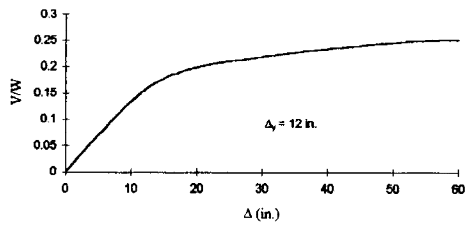
Using push-over static analysis method, V/W vs. Δ diagrams were obtained for the frames (Fig. 4). As can be seen from fig. 4, yielding displacements (Δ_y) were found to be as 4 in., 8 in., and 12 in. for the 3-story, 6-story, and 9-story frames, respectively.



a. 3-story frame



b. 6-story frame



c. 9-story frame

Figure 4. V/W vs. Δ diagrams

Strain Levels

Strain level diagrams were obtained for μ=3 and 5 (Fig. 5).

CONCLUSIONS

Several conclusions can be drawn from the above study:

1) The ductility of hybrid frames is influenced significantly by the confinement of concrete columns. It is shown that the studied frames have large strain demand on composite columns for ductility of 5.
2) The energy input is very sensitive to ground motion type in the three and six-story frames.
3) The amount of energy dissipated through inelastic deformation depends on the type of ground motion, but the amount of energy dissipated through the viscous damping is not sensitive to the type of ground motion.

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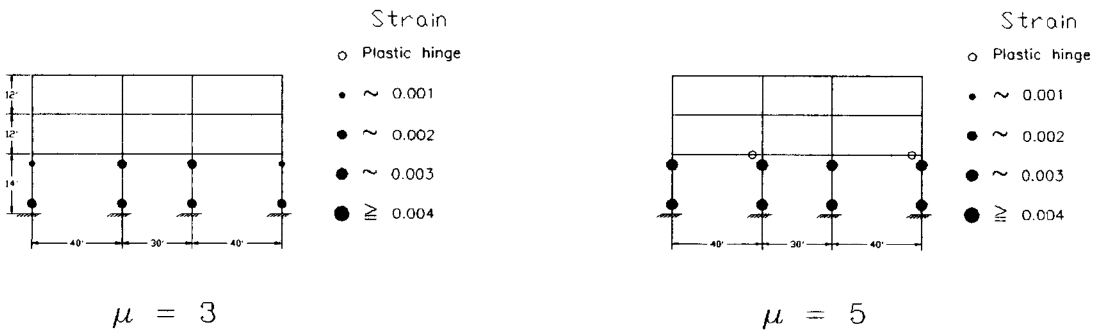
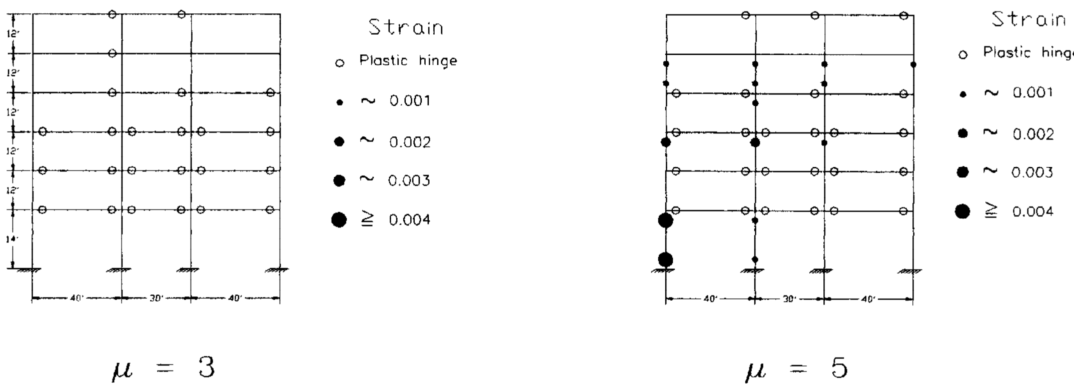
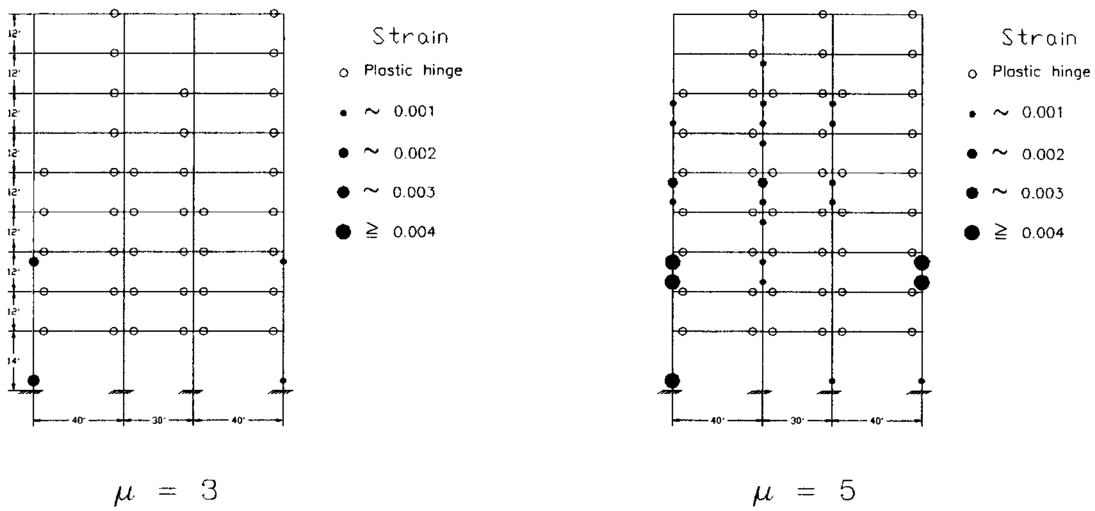


a. Strains for 3-story frame



b. Strains for 6-story frame



c. Strains for 9-story frame

Figure 5. Strain levels

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