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ANALYSIS OF BUILDING STRONG-MOTION RECORDS FROM THE 1994 NORTHRIDGE, CALIFORNIA EARTHQUAKE

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ABSTRACT

Over 150 instrumented buildings throughout Los Angeles area recorded roof level accelerations greater than 0.25 g during the Northridge, California earthquake of January 17, 1994. Some of these buildings are extensively instrumented by the California Strong Motion Instrumentation Program (CSMIP) and others have minimal instruments as required by the building code. Many of the buildings recorded high levels of structural response and some suffered structural damage. Analysis of processed data from several buildings in the San Fernando Valley indicates that short-period buildings such as shear wall buildings experienced large forces and relatively low story drift during the Northridge earthquake. On the other hand, longer period buildings (periods between 1 and 5 seconds) such as steel or concrete moment-frame buildings, experienced large story drifts. For this earthquake, accelerations did not always amplify from base to roof, especially for flexible structures like moment-frame buildings, but the displacements were always larger at the roof. The drifts at the roof level of many of the moment-frame buildings were larger than the drift limit for working stress design in the building code.

KEYWORDS

Northridge Earthquake; Strong-Motion Record; Building Period; Drift.

INTRODUCTION

The 6.7M (moment magnitude) earthquake that occurred near Northridge, California on January 17, 1994 produced an important set of strong-motion recordings from more than 250 ground-response stations, 400 buildings and 50 other structures. The California Strong Motion Instrumentation Program (CSMIP) recovered records from 116 ground-response stations and 77 extensively-instrumented structures. The extensively-instrumented structures include 57 buildings, 12 dams, 5 major freeway interchanges, a toll bridge, an airport control tower and a power plant.

Table 1
CSMIP and Code–Instrumented Building Data from the Northridge Earthquake

Sta. No.	City	Bldg Name	Lateral System*	No. of stories	Max. Horiz. Accel. (g) ** H1roof(g)	H1base(g)	H2roof(g)	H2base(g)
24514	Sylmar	Hospital	S/CSW	6	1.50	0.80	0.75	0.38
24370	Burbank	Commercial	SMF	6	0.28	0.21	0.47	0.36
24385	Burbank	Residential	CSW	10	0.77	0.34	0.53	0.27
24322	Sherman Oaks	Commercial	CMF	13	0.46	0.45	0.26	0.22
24464	N. Hollywood	Hotel	CMF	20	0.65	0.32	0.33	0.12
24386	VanNuys	Hotel	CMF	7	0.56	0.39	0.58	0.45
24643	Los Angeles	AveofStars	SMF	19	0.60	0.20	0.32	0.32
C016	Los Angeles	AveofStars#2	SMF	36	0.30		0.34	
C253	Los Angeles	Beverly#1	SMF	10	0.43	0.16	0.47	0.22
C135	Woodland Hills	Canoga#1	SMF	17	0.37		0.23	
C133	Woodland Hills	Canoga#2	SMF	17	0.45		0.26	
C106	Woodland Hills	Canoga#3	CMF	15	1.02		0.43	
C173	N. Holloywood	Lankershim#1	SMF	7	0.33		0.30	
C083	N. Hollywood	Lankershim#2	SMF	8	0.23	0.21	0.31	0.30
C215	N. Holloywood	Magnolia#1	CSW	12	0.71		0.42	
C001	Northridge	Oakdale#1	SMF	10	0.26		0.46	
C024	Los Angeles	Olympic#1	SMF	9	0.69		0.51	
C289	Los Angeles	Olympic#2	SMF	11	0.65		0.97	
C250	Los Angeles	Olympic#3	SMF	10	0.70		0.65	
C161	Los Angeles	Olympic#4	SMF	12	0.38		0.55	
C210	Woodland Hills	Oxnard#2	SMF	20	0.29		0.31	
C232	Woodland Hills	Oxnard#3	CSW	17	0.51		0.71	
C246	Woodland Hills	Oxnard#4	SMF	12	0.24	0.32	0.32	0.41
C130	Northridge	Roscoe#1	CMF	7	0.58	0.42	0.39	0.39
C233	Van Nuys	Sherman#1	CSW	12	0.64	0.27	0.53	0.37
C088	Encino	Ventura#04	SMF	13	0.39		0.44	
C206	Woodland Hills	Ventura#05	CMF	12	0.28	0.39	0.34	0.49
C014	Sherman Oaks	Ventura#06	SMF	15	0.48	0.45	0.25	0.36
C126	Sherman Oaks	Ventura#07	SMF	21	0.46		0.34	
C132	Sherman Oaks	Ventura#08	CSW	8	0.48		0.77	
C201	Encino	Ventura#09	CMF	12	0.47	0.46	0.28	0.26
C015	Tarzana	Ventura#10	SMF	10	0.50	0.47	0.24	0.37
C085	Woodland Hills	Victory#1	SMF	12	0.51		0.38	
C125	Woodland Hills	Victory#2	CSW	8	0.77		0.66	
C043	Los Angeles	Wilshire#01	SMF	23	0.30		0.62	
C040	Los Angeles	Wilshire#02	CSW	17	0.43		0.53	
C165	Los Angeles	Wilshire#03	SMF	17	0.28		0.24	
C168	Los Angeles	Wilshire#04	SMF	21	0.24		0.37	
C066	Los Angeles	Wilshire#05	SMF	14	0.30		0.28	
C042	Los Angeles	Wilshire#06	SMF	17	0.21		0.29	
C067	Los Angeles	Wilshire#07	SMF	14	0.29		0.34	
C041	Los Angeles	Wilshire#08	CSW	18	0.33	0.17	0.33	0.18
C009	Los Angeles	Wilshire#09	SMF	21	0.19	0.22	0.17	0.19
C131	Los Angeles	Wilshire#10	SMF	24	0.24	0.23	0.35	0.27

* SMF – steel moment frame; CMF – concrete moment frame; CSW – concrete shear wall
** H1, H2 indicate the two principal directions of the building.

Copies of the records are presented in a CSMIP data report (Shakal, Huang and others, 1994).

Many cities in California have adopted provisions in their local building codes that require high rise building owners to install one or three accelerographs. These high rise buildings are over six stories in height with a floor area greater than 60,000 square feet, or over ten stories in height. In the Los Angeles metropolitan area, there are code-instrument records from 350 or more buildings. Significant response data were recorded at many of these buildings during the Northridge earthquake. In cooperation with the City of Los Angeles, the National Science Foundation, Agbabian Associates and other groups, CSMIP is collecting, archiving and processing these records.

As of January 1996, records from 40 code-instrumented buildings and 57 extensively-instrumented buildings of the CSMIP network have been digitized and processed (Darragh and others, 1994a-g, 1994h, 1995). Table 1 lists the 44 of these buildings that were selected for this study and the peak acceleration values recorded in each building. The building heights range from 6 to 36 stories and the maximum roof acceleration ranges from 0.19 to 1.5g. These buildings are located in the San Fernando Valley and West Los Angeles where many steel buildings were damaged during the Northridge earthquake. The type of lateral force resisting systems for these buildings includes steel moment frame, concrete moment frame, and concrete shear wall. No attempt was made to divide the steel moment frame category into braced, perimeter and distributed moment frames.

Several buildings in the San Fernando Valley were instrumented with limited instrumentation at the time of the 1971 San Fernando earthquake. Two of these buildings, one in Van Nuys and one in North Hollywood, have since been extensively instrumented by CSMIP. In the Northridge earthquake the Van Nuys building, a non-ductile concrete moment frame structure, recorded a peak horizontal acceleration of 0.45g at the base and 0.58g at the roof, and suffered structural damage. The North Hollywood building, a ductile concrete moment frame structure, recorded 0.32g at the base and 0.65g at the roof, and suffered non-structural damage. These peak values are about twice those recorded at these buildings during the 1971 San Fernando earthquake.

Many code-required and owner-instrumented buildings are located in the southern part of the San Fernando Valley. Some buildings had accelerographs on the roof, an intermediate floor and the base, but some had only one accelerograph on the roof. The usefulness of these records may be limited, but they still provide valuable information on the building response. The steel buildings are being or have been inspected for cracked joints. These records have been used to guide the inspection process and to verify the accuracy of present analytical tools in predicting the extent and severity of joint damage (Uang and others, 1995).

ANALYTICAL METHODS

The building fundamental periods can be identified by visual inspection of the roof acceleration and displacement records (Housner and Jennings, 1982). For flexible structures, the higher mode motions can be dominant in the acceleration records, so it is important to look at displacement records to reduce the possibility of confusion. For stiff structures, the fundamental period can be easily be determined from the acceleration records. The periods for those buildings with both the base and the roof records can also be confirmed by computing the transfer function between the roof and the base records. Some buildings exhibited nonlinear response and their fundamental periods were lengthened during the shaking. The period used herein for these building is the lengthened value which is associated with the largest displacement response.

The total drift at the roof is obtained by computing the relative displacement between the roof and the base displacement records if both records are available. For the flexible buildings with only a roof record, the total drift can be estimated from the roof displacement record because the roof displacement is mostly due to the structural response. On the other hand, it is more difficult to estimate the drift for stiff buildings with only the roof record.

As an example, Figure 1 shows the acceleration records obtained at the roof level of a 8-story parking structure (concrete shear walls) and a 12-story office building (steel frame) in the Woodland Hills area of the San Fernando valley where many buildings were damaged. The two buildings are next to each other. The absolute displacements integrated from the acceleration records are also shown in the figure. The building period is about 0.7 second for the parking structure, determined from the acceleration record, and about 2.9 seconds for the office building, clearly shown in the displacement record. The large pulses in the displacement record from the parking structure are due to the ground movement and one can estimate that the ground displacement is similar to the displacement record on the roof. On the other hand, the roof displacement of the office building is dominated by the building response, so the drift can be estimated from the roof displacement record to be about 42 cm. In sum, the parking structure experienced larger forces (0.77g) than the office building (0.51g), but had much smaller total drift.

RESULTS

The 44 buildings in Table 1 are divided into two groups: moment frames and shear walls. Concrete moment frame buildings are generally as flexible as the steel moment frame buildings, so they are in the same group. Correlation analyses for building period and roof drift are carried out and the results are compared with some simple formulas.

Building Period

The building fundamental periods for 35 moment-frame buildings and 9 shear-wall buildings are plotted against the number of stories (N) in Figure 2 for both horizontal directions. For moment-frame buildings, all the periods are larger than 0.1 N. Many of the buildings that are less than 24 stories had periods larger than 0.2 N. On the other hand, for concrete shear wall buildings, the periods fit well with 0.1 N.

Roof Drift

The total drift at the roof level for 35 moment-frame buildings are plotted against the building height (H) in Figure 3. The drift limit in the building code is approximately 0.004 H for these buildings. Many drifts in Figure 3 were larger than this value. Since the designs of moment-frame buildings are mostly controlled by drift, structural members in some of these moment-frame buildings may have been beyond the elastic limit during the earthquake. However, these drifts were not as large as the value of 3Rw/8(0.004H) used for deformation compatibility in the code. The drifts for four shear-wall buildings, which can be computed from the roof and the base records, are also shown in Figure 3, and they are less than the code drift limit.

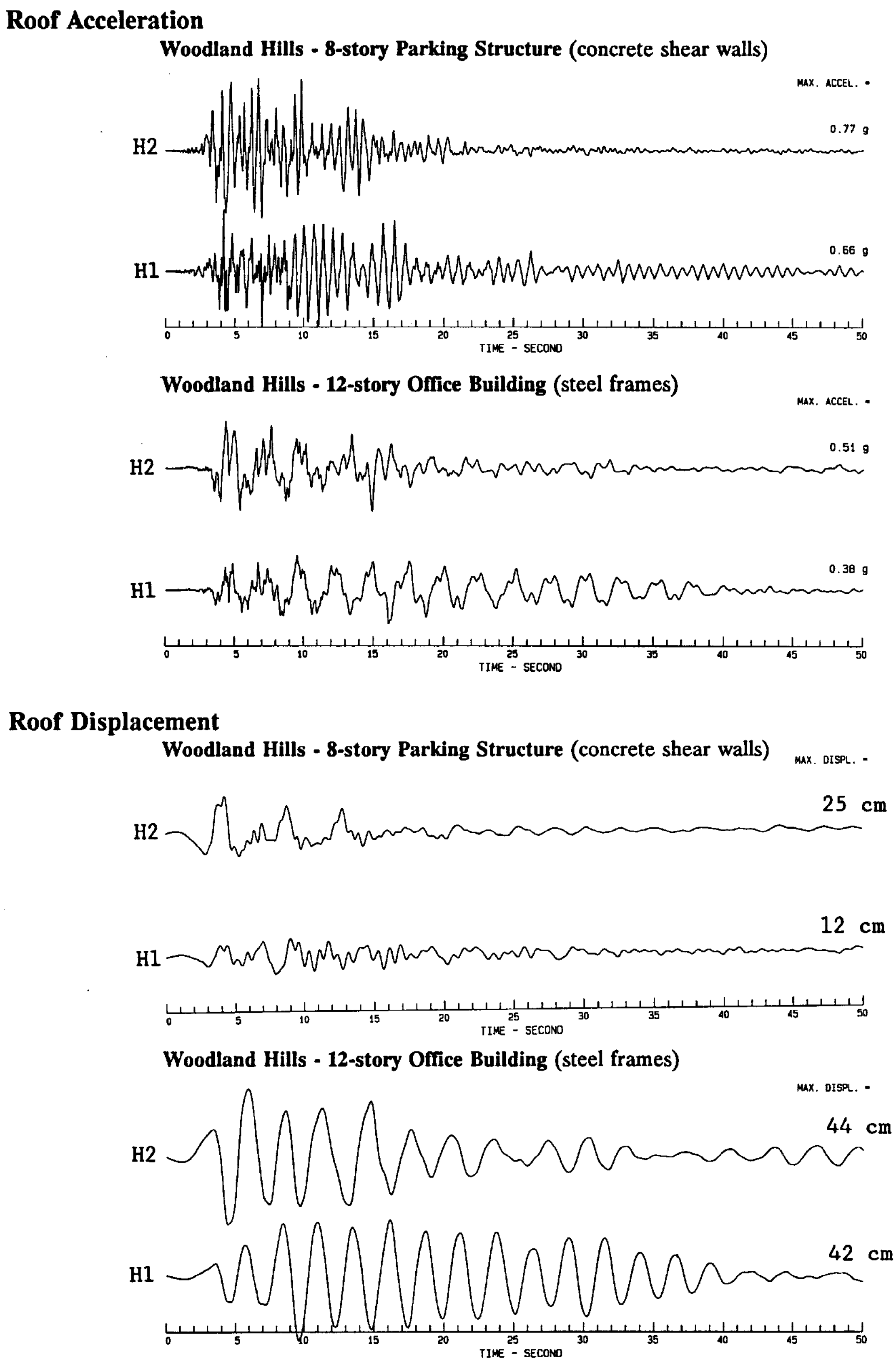
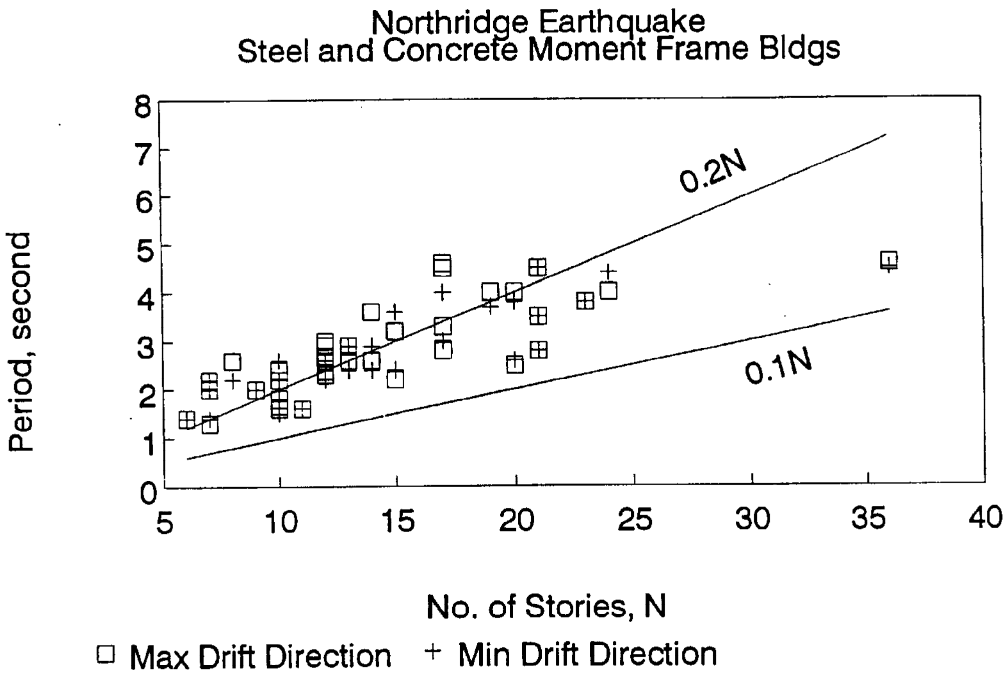
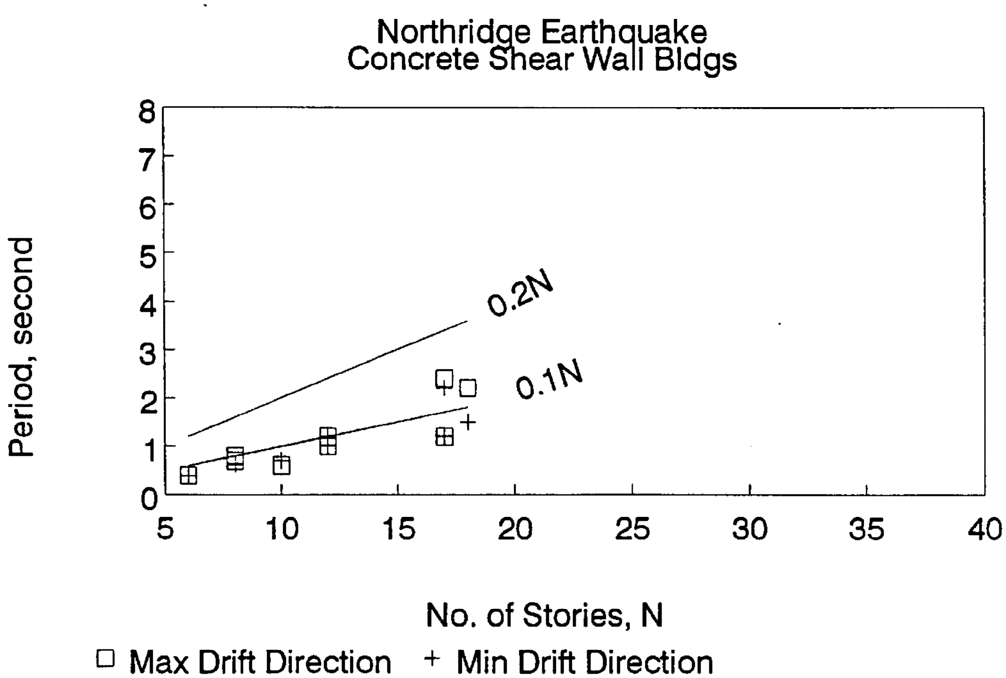


Figure 1. Horizontal roof accelerations and displacements for an 8-story parking structure and a nearby 12-story office building in Woodland Hills, on the south side of San Fernando Valley, for the Northridge earthquake.

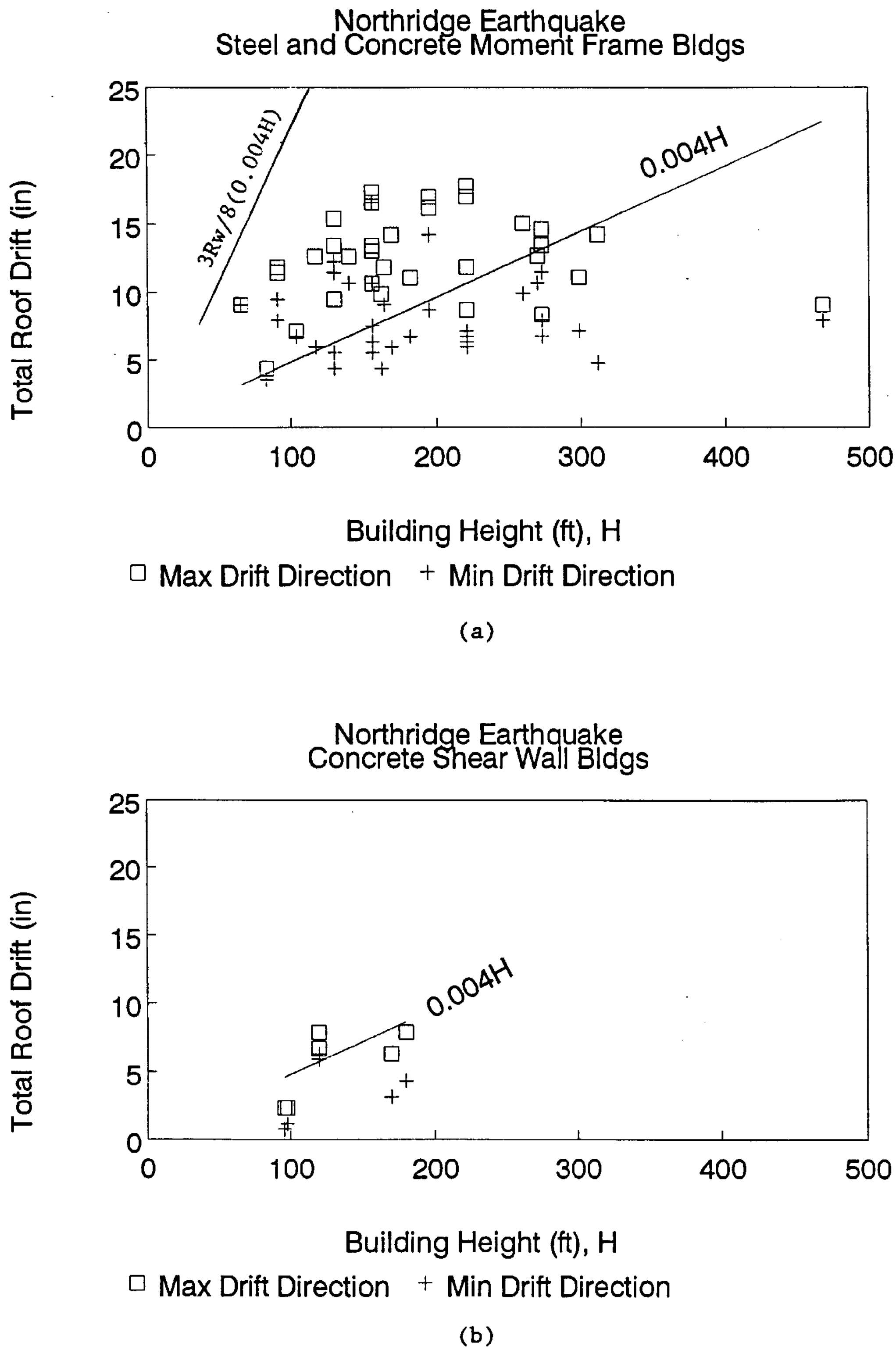


(a)



(b)

Figure 2. Building periods versus number of stories for (a) 35 moment-frame buildings, and (b) 9 concrete shear wall buildings in the Northridge earthquake.



(a)

(b)

Figure 3. Total drifts at roof versus building height for (a) moment-frame buildings, and (b) concrete shear wall buildings in the Northridge earthquake.

SUMMARY

The processed records from 44 instrumented buildings for the Northridge earthquake are analyzed to determine fundamental periods and total roof drifts. For moment-frame buildings, both steel and concrete, the fundamental periods are all larger than would be predicted by the commonly-used formula 0.1 N, where N is the number of stories. In fact, many of the moment-frame buildings of less than 24 stories height had periods more than twice the 0.1 N. The roof drifts for many of these buildings were larger than the drift limit for working stress design in the building code.

Records from buildings in the epicentral area indicate that short-period buildings such as shear wall buildings experienced large forces and relatively low inter-story drift. On the other hand, long-period buildings (periods between 1 and 5 seconds) such as steel or concrete moment-frame buildings experienced large roof drifts. For this earthquake, accelerations did not always amplify from base to roof for flexible structures like the moment-frame buildings, but the displacements were always larger at the roof.

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