

# On the Differential Displacements at the Base of the Van Nuys 7-Story Hotel During the January 17, 1994 Northridge Earthquake

Farzad Naeim, Ph.D., S.E., M.EERI\*

The Van Nuys 7-Story Hotel (CSMIP Station No. 24386) was damaged during both the 1971 San Fernando and the 1994 Northridge earthquakes. The seismic performance of this building during the Northridge earthquake has been the subject of numerous studies. None of the previous studies, however, have attempted to explain the reason for and the consequences of a differential N-S displacement of about 2.5 cm (1 in.) that is suggested by the records obtained from the sensors at the base of this building. The purpose of this paper is to explain this phenomena. It is shown that this difference is a result of the rigid-body rotation of the foundations and the slab-on-grade. This is the reason why the slab-on-grade suffered no damage during the Northridge earthquake. In other words, the differential movement observed is not relative motion and did not cause diaphragm forces in the slab-on-grade. Simple identification and elimination of the rigid body rotation of the slab-on-grade results in corrected motions that are identical in amplitude, phase, and frequency content. This exercise illustrates the importance of the strong motion records obtained from the instrumented buildings as well as the degree of care that must be applied in interpretation of their physical meaning.

## INTRODUCTION

The Van Nuys 7 Story Hotel is a reinforced concrete structure with no basements. It was designed in 1965 and constructed in 1966 (Figure 1). Its vertical load carrying system consists of 8 in. and 10 in. concrete slabs supported by concrete columns, and spandrel beams at the perimeter. The lateral load resisting system consists of interior column-slab frames and exterior column-spandrel beam frames. The foundation consist of 38 inch deep pile caps, supported by groups of two to four poured-in-place 24 inch diameter reinforced concrete friction piles. The building is instrumented by the Strong Motion Instrumentation program of the California Division of Mines and Geology (SMIP/CDMG) and was one of the 20 extensively instrumented buildings documented in

---

\* Director of Research and Development, John A. Martin and Associates, Inc., Los Angeles, California.

the SMIP Information System CD-ROM (Naeim, 1997). Sketches of plan and elevation of the building showing the location of sensors are presented in Figure 2.

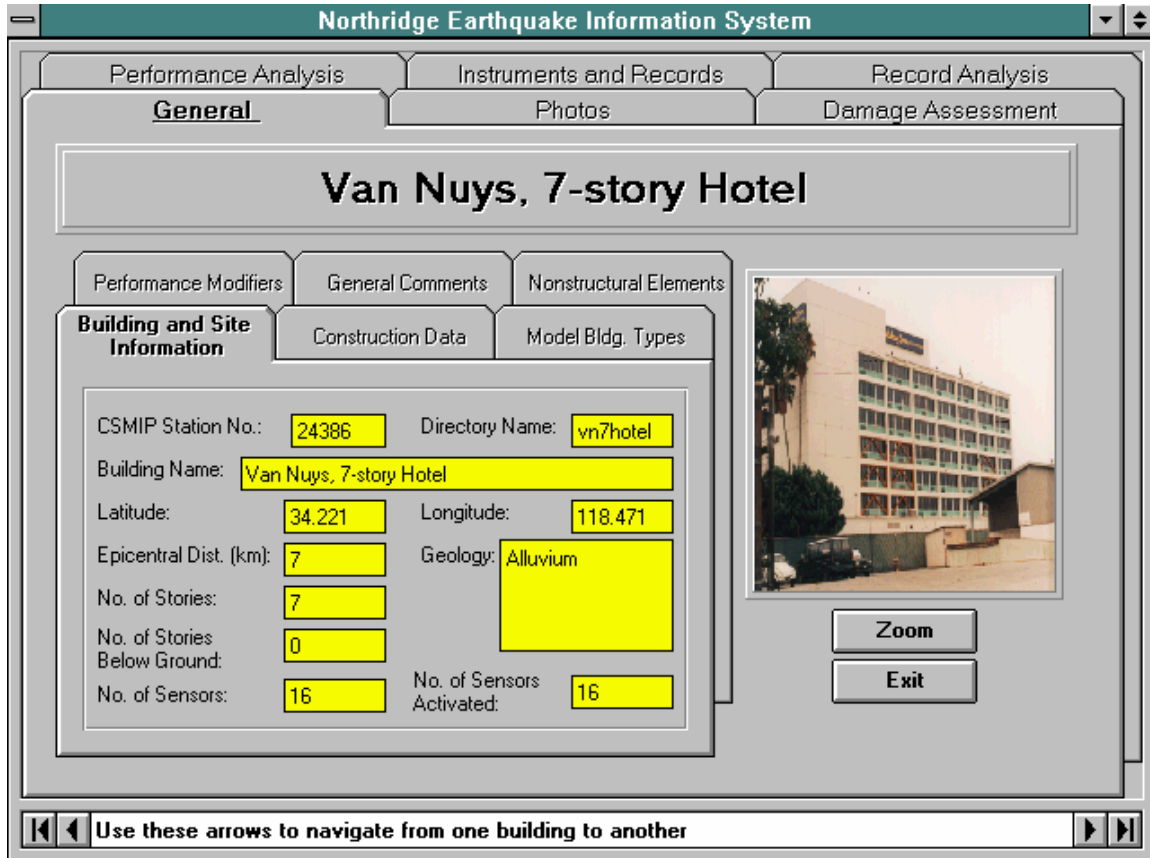


Figure 1. A view of the 7-story Van Nuys Hotel

The largest peak horizontal accelerations recorded at the base (Channel 16, E-W) and at the roof (channels in both directions) are 0.45g and 0.58g, respectively. The largest velocity recorded at the roof is about 77 cm/sec.

Performance analysis calculations for the building (Naeim, 1997) indicate a 0.33g base shear seismic coefficient in response to Northridge ground motions. The maximum base shear experienced by the building in the E-W direction is significantly larger than the 1964 UBC strength design base shear of about  $1.4 \times 0.05W = 0.07W$  and somewhat larger than the UBC-94 value of about  $1.4 \times 0.15 = 0.21W$  for a non-ductile moment resisting frame system. The building experienced significant deformation particularly in the E-W direction with an overall drift index exceeding one percent of the height.

The building had suffered minor structural damage and extensive nonstructural damage during the 1971 San Fernando earthquake that was subsequently repaired. It experienced heavy damage during the 1994 Northridge earthquake where the South side exterior columns at fourth floor failed in shear (Figure 3).

Figure 2. Sketch of the building showing the location of sensors

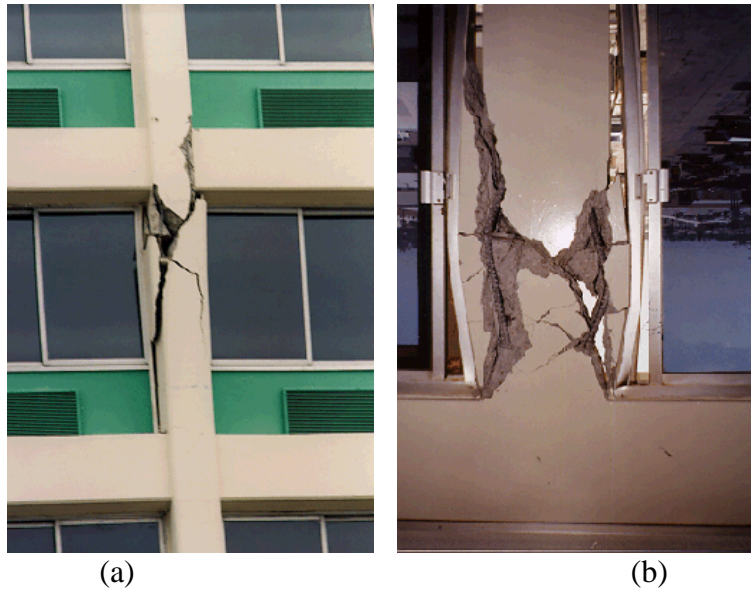


Figure 3. Shear failure of column at the fourth floor  
(a) view from outside); (b) view from inside

The author visited the building shortly after the Northridge earthquake and observed no significant sign of damage at the ground floor (i.e. slab on-grade).

### **DIFFERENTIAL DISPLACEMENTS AT THE BASE**

Subsequent to the publication of the SMIP Information System CD-ROM, several of the CD-ROM users contacted the author and inquired about the apparent “relative slab movement” at the base suggested by the records obtained from channels 1, 13, and 14 and asked about possible damage status because of these differences in movement. Some even suggested phasing and spatial variation of earthquake waves as the possible source of these differences.

The sensor for Channel 14 is placed on a pile-cap at the base of the moment frame. The sensor for Channel 13 is placed on the slab-on-grade adjacent to the sensor for Channel 14. The sensor for Channel 1 is placed on the slab-on-grade at a distance of 133.3 ft from these two sensors. All three of these sensors are oriented to record the motion in the N-S direction. The sensor for Channel 16 is placed at the same location of the sensor for Channel 14 but it is oriented to record E-W motions.

The displacements obtained by integrating acceleration records of sensors 1, 13, and 14 are shown in Figure 4. These displacement traces are perfectly in-phase and this nullifies spatial variation and phase lag as the causes of any differential motion. Furthermore, they exhibit identical frequency content. If we plot the difference in Channel 1 and Channel

13 displacements (Figure 5), we notice a maximum difference of over 2cm (about 1 in). These differences are mainly in the amplitudes of in-phase peaks (Figure 6).

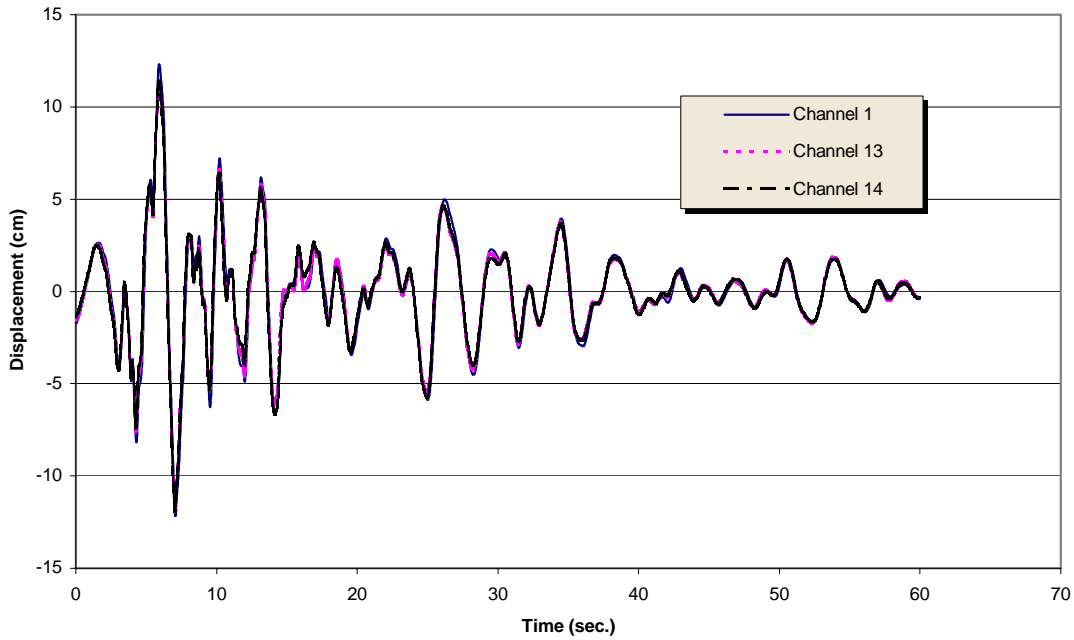


Figure 4. Displacement traces obtained by integration of accelerations recorded at Sensors 1, 13, and 14.

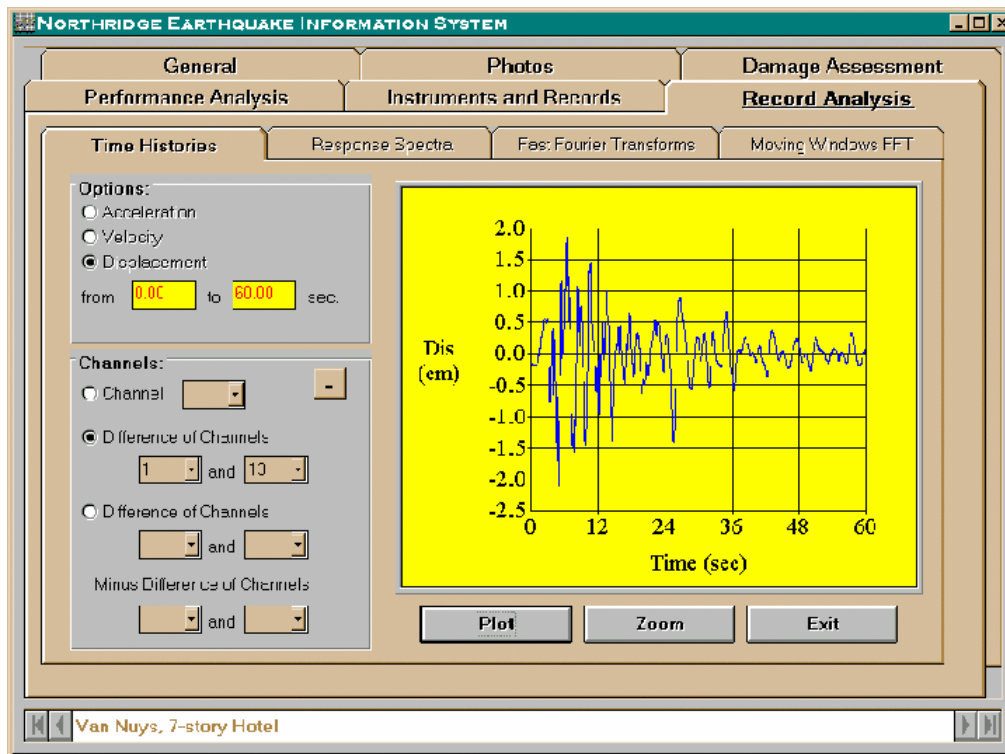


Figure 5. Difference of displacements between sensors 1 and 13.

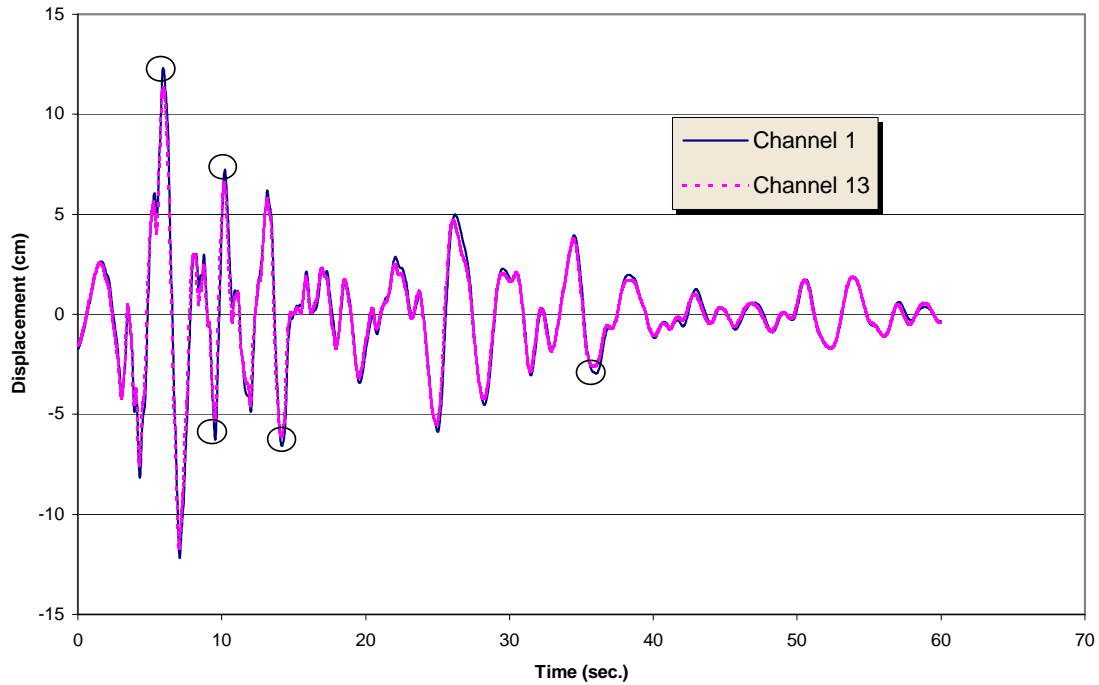
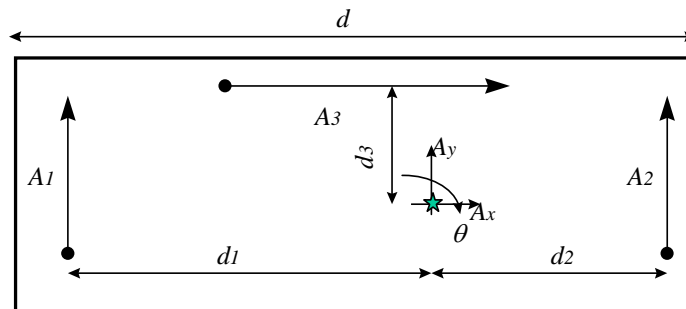


Figure 6. Displacement traces of Channels 1 and 13

To show that this difference is due to rigid-body rotation, let us assume that the slab-on-grade is perfectly rigid in its own plane. Then if  $A_1$ ,  $A_2$  and  $A_3$  are the values of response measured by sensors 1, 13 and 16, respectively, and  $d_1$ ,  $d_2$  and  $d_3$  are the respective distance of these sensors from the center of mass, then  $A_x$ ,  $A_y$  and  $A_\theta$  (the response of the center of mass in the  $x$ ,  $y$ , and  $\theta$  directions) are related to  $A_1$ ,  $A_2$ , and  $A_3$  by the following set of equations:



$$A_1 = A_y + d_1\theta$$

$$A_2 = A_y + d_2\theta$$

$$A_3 = A_x + d_3\theta$$

In matrix form,

$$\begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix} = \begin{bmatrix} 0 & 1 & d_1/d \\ 0 & 1 & -d_1/d \\ 1 & 0 & d_3/d \end{bmatrix} \begin{Bmatrix} A_x \\ A_y \\ \theta d \end{Bmatrix} \text{ or } \begin{Bmatrix} A_x \\ A_y \\ \theta d \end{Bmatrix} = \begin{bmatrix} 0 & 1 & d_1/d \\ 0 & 1 & -d_1/d \\ 1 & 0 & d_3/d \end{bmatrix}^{-1} \begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix}$$

By simply assuming the center of mass of the slab to be at its geometrical center, the distances  $d_1$ ,  $d_2$  and  $d_3$  are 160 ft., 51.25 ft., and 80 ft., respectively. Hence, the above equation becomes

$$\begin{Bmatrix} A_x \\ A_y \\ \theta d \end{Bmatrix} = \begin{bmatrix} 0 & 1 & 0.3203 \\ 0 & 1 & -0.3203 \\ 1 & 0 & 0.1656 \end{bmatrix}^{-1} \begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix}$$

Now if we correct the displacement traces obtained from channels 1, 13 and 14 to eliminate rigid-body torsion obtained from the above equation, the difference in displacement of these channels is virtually eliminated (Figure 7).

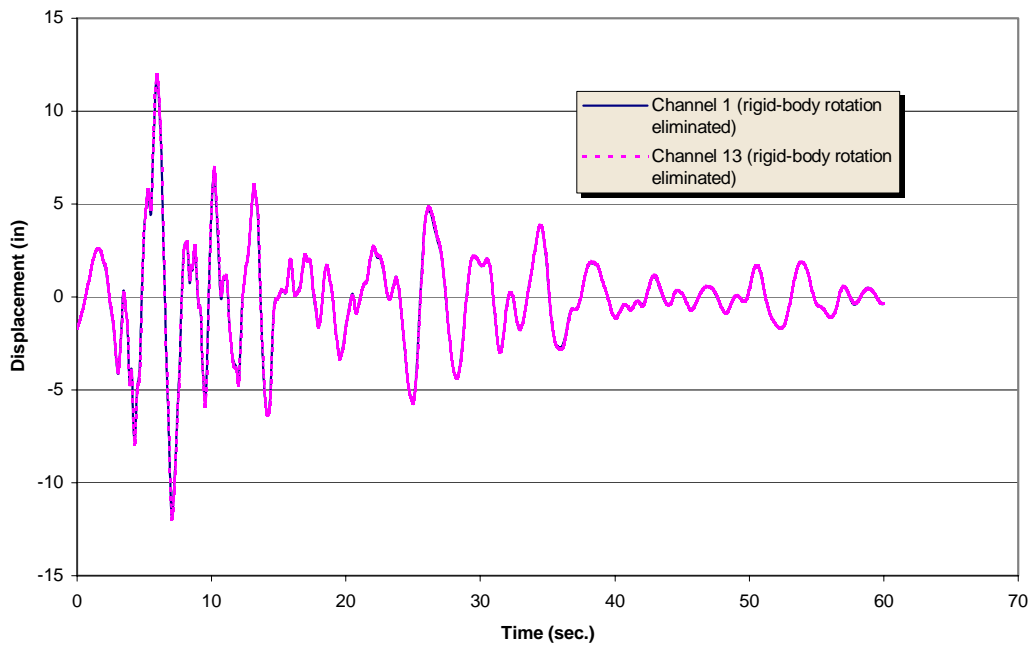


Figure 7. Displacement traces of sensors 1, 13 match after removal of rigid-body rotation

The remaining difference of 0.6 cm (0.24 in) is easily explained by imperfect initial conditions of the displacement traces and the round off errors of finite sampling rate (50 samples per second). The initial displacements and their derivatives for neither trace is zero and non-equal to each other due to the missing front pieces of the accelerograms which have occurred before the accelerations have reached the level of triggering the sensors.

## CONCLUSION

The reason behind the differences in base displacements obtained from the three sensors at the base of the Van Nuys 7-story Hotel during the 1994 Northridge earthquake were investigated. It was shown that these differences were due to the rigid-body rotation of the building base caused by the rotational components of the earthquake ground motion. These differences did not cause relative displacements in the base floor system (slab-on-grade, grade-beams, and pile caps) and that is why no significant damage was observed in these portions of the structure.

## References

Naeim, Farzad (1997), *Performance of Extensively Instrumented Buildings During the January 17, 1994 Northridge Earthquake –An Interactive Information System--*, Report No. 7530.68/97, John A. Martin and Associates