SPECTRAL ANALYSIS OF THE 1979 IMPERIAL COUNTY SERVICES BUILDING RECORDS

by

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ABSTRACT

The time variation of the response of the Imperial County Services Building (ICSB) during the El Centro, CA, earthquake of October 15, 1979, is investigated. The response of this six-story reinforced concrete frame and shear wall building is of interest to the earthquake engineering community since it is the first recorded in a building which suffered major structural damage due to strong ground motion. The principal structural damage consisted of the failure at the base level of the first story columns at the east end. Because the building was extensively instrumented in accordance with its dynamic characteristics, a concise presentation of time-varying spectra generated for the acceleration response records illustrates interesting features of the response: the translational and torsional responses and pile-foundation-structure interaction.

INTRODUCTION

The ICSB, shown in Figure 1, was designed to the 1967 Uniform Building Code and constructed in 1971. The building was supported by Raymond step-taper concrete piles which extended into alluvium. Lateral loads were resisted in the east-west (E-W) direction by reinforced concrete moment resisting frames. In the north-south (N-S) direction, lateral loads were resisted in the upper stories above the second floor by exterior facade full width shear walls at the east and west ends. Below the second floor, the full width exterior shear walls were discontinued and lateral loads were transferred through the second floor slab to four, first story center bay shear walls located in the interior of the building.

At the time of the 1979 earthquake, the strong motion building instrumentation consisted of a 13-channel CRA-1 accelerograph system. In addition, a triaxial SMA-1 accelerograph was located at the ground level approximately 103 meters east of the ICSB to record the "free field" motion. The locations of the sixteen accelerometers are indicated in Figure 1. There were no vertically oriented accelerometers above the base of the building. During the 1979 earthquake, all building and free field instruments produced records of almost 60 seconds in duration. Maximum horizontal accelerations were 0.24g at the free field site, 0.34g at the base, and 0.58g at the roof.

Time-Frequency Domain Analysis

To investigate the response of the ICSB, time-varying spectra are generated for all building and nearby free field acceleration records which decompose the accelerations into a function of time and frequency. Comparisons of the upper story records with the base and free field records indicate that the base amplified frequencies of the building. Hence the response records, rather than the corresponding transfer functions, are analyzed. To improve accuracy over the traditional approach of generating spectra using a moving rectangular time window, a Gaussian window (1) centered at a given frequency, f_o, and incremented in the frequency domain is used to generate the spectra. Derived is the envelope of the acceleration (2), $S_A(t_o, f_o)$, at a given time, t_o, and a given frequency, f_o, given as

$$S_A(t_o, f_o) = \left|\int_{-\infty}^{\infty} M(f)H(f-f_o)\exp\left[i2\pi f t_o\right]df\right| \qquad (1)$$

where

$M(f)$ = Fourier spectrum of the analytic signal, $a(t)-a_1(t)$

$H(f-f_o)$ = weighting function = $(2\alpha)^{\frac{1}{4}} \exp[-\pi\alpha(f-f_o)^2]$

$a(t)$ = acceleration time history

$a_1(t)$ = Hilbert transform of $a(t)$

$\alpha = \Delta f$ = bandwidth of the weighting function

The frequency (or time) resolution and the amplitude (envelope) are functions of the bandwidth Δf of the weighting function. Unless otherwise indicated, a value of Δf of 0.2Hz was used to generate spectra for the first 20.48 seconds of all records. Spectra are shown at representative times in Figures 2, 3, and 5 for the E-W, N-S, and vertical directions, respectively. The times shown represent the mid-interval time of an equivalent $1/\Delta f$ time window. In these figures, the spectra for each acceleration component are denoted by the direction of the component, the floor level, and the location in the building. For example, N/R/W denotes the acceleration spectra for the N-S direction, at the Roof level, and at the West end of the building. Results of ambient vibration tests performed on the ICSB prior to (3) and after (4) the 1979 earthquake are also discussed below.

Building Response in the E-W (Frame) Direction

Spectra in the E-W direction for the roof (E/R/C), fourth floor (E/4/C), second floor (E/2/C), base (E/G/E) and corresponding free field (FF092) components are presented at 2.5, 5, 7.5, 10, 15, and 20 seconds in Figure 2. At each time, the spectra of the instrumented floor levels and of the free field site are arranged column-wise to aid in the recognition of modal response and soil-structure interaction. The spectra show that the E-W response is governed primarily by the first two modes, whose time variation was determined from visual inspection of the spectra and is graphed in Figure 4. Multiple values for the modal frequencies are shown at those times in Figure 4 where changing response was indicated in the spectra by a broad frequency band or by closely spaced multiple peaks.

The spectra at 5 seconds show that, at the onset of large amplitude ground and building motion, the first two modes are excited. The frequency of the first mode decreased from the prequake ambient vibration test frequency of 1.55Hz (3) to about 0.78Hz to 0.98Hz. The second mode is indicated by spectral amplification in the upper story spectra at about 3.13Hz to 3.32Hz. The spectral amplitude of the second mode at the roof is comparable to the magnitude of the first mode. The spectrum at 5 seconds at the base of the building also shows a pronounced peak at 3.13Hz to 3.32Hz which corresponds to the second mode of the building and is not amplified in the free field spectrum at this time. Hence the base is vibrating in-phase with the second floor.

The spectra at 7.5 seconds and thereafter show that the fundamental frequency decreased to 0.59Hz, which was a decrease to about 0.40 times the prequake ambient vibration test frequency. The spectra at 7.5 seconds indicate the second mode frequency decreased to 2.34Hz, which is also amplified in the base spectrum. The spectra at 10 and 15 seconds show fluctuations in the second mode about 2Hz and after 15 seconds, the second mode frequency is about 2.13Hz to 2.34Hz. At and after 7.5 seconds, however, the contribution of the second mode is small relative to the first mode. The base and free field spectra after 10 seconds are similar in amplitude and frequency content suggesting little influence of soil-structure interaction. The fundamental frequency of 1.20Hz determined during the postquake ambient vibration test (4) indicates that stiffness degradation in the E-W direction had occurred as a result of the 1979 earthquake.

Building Response in the N-S (Shear Wall) Direction and Torsional Response

Spectra for the recorded responses in the N-S direction are shown in Figure 3 at 5, 10, 15, and 20 seconds. At each time, the spectra at the west end, center, and east end of the building are shown row-wise while the spectra at the instrumented floor levels are shown column-wise. Torsional response appears in spectra generated for the N-S records and also in spectra generated for the differential accelerations between the west and east ends at the base, second floor, and roof level included in Figure 3. The spectra in Figure 3 indicate that the first two N-S translational and first two torsional modes are excited. The time variation of the fundamental N-S translational and torsional modes is shown in Figure 4 and time variation of the second modes is discussed below.

At the onset of large amplitude motion (spectra at 5 seconds), the west end, center, and east end appear to vibrate at the same fundamental translational frequency of about 1.56Hz to 1.95Hz which is a decrease from the prequake ambient vibration test frequency of 2.24Hz (3). A second translational mode at 3.91Hz is evident in the spectra at the west end, center, and east end. The spectra at 10 seconds indicate that the west and east ends are vibrating at different fundamental frequencies of 1.76Hz and 1.37Hz, respectively, but the frequency of the second translational mode (2.39Hz) is the same at both ends. A first torsional mode frequency of 1.56Hz is evident since the east and west ends appear to be vibrating out-of-phase at this frequency. The influence of the pile-foundation is evident since both base spectra amplify the second translational mode frequency that is not evident in the free field (FF002) spectra at 5 and 10 seconds.

The spectra at 15 and 20 seconds show distinct differences in the responses at the west end, center, and east end. Such differences are expected since major structural damage occurred in the first story columns at the east end while only minor structural damage was evident in the first story at the west end. Variations in the responses at the west end, center, and east end are evident by the differences in the N-S fundamental frequencies at the west end (1.56Hz to 1.76Hz), center (0.98Hz) and east end (0.98Hz). The fundamental frequencies at the west and east ends decreased to about 0.70 times and 0.40 times, respectively, the prequake ambient vibration test frequency of 2.24Hz. The first torsional mode frequency of 1.37Hz indicates a decrease to 0.48 times the prequake ambient vibration test frequency of 2.85Hz (3). The amplified frequency band between 3Hz and 3.5Hz indicates a second translational and a possible second torsional mode. At all times shown in Figure 3, the spectra at the base at the west and east ends are essentially identical in amplitude and frequency content and also indicate that pile-foundation-interaction occurred since the base motions amplified frequencies corresponding to the building response which are not evident in the free field spectra.

<u>Building Base and Free Field Responses in the Vertical Direction</u>

Accelerations were recorded in the vertical direction only at the base at the east end (U/G/E) and at the nearby free field site (FF UP). Spectra in the vertical direction for these components are shown in Figure 5 at 1.25, 2.5, 5, 7.5, 10, and 20 seconds. Because the largest accelerations occurred in the vertical direction early in the earthquake, spectra were also generated for the base and free field components for the first 2.56 seconds using a frequency bandwidth of Δf = 0.4Hz and the time of 1.25 seconds in Figure 5 corresponds to these spectra. From the spectra, it can be readily seen that (1) the strongest motion (largest accelerations) occur approximately between 2.5 and 7.5 seconds, (2) amplitudes are generally larger at the free field than at the base, and (3) frequencies primarily between 4Hz and 12Hz are amplified in both components.

Conclusions

The purpose of instrumenting buildings such as the ICSB is to give insight into full-scale response mechanisms. The time-varying spectra generated for the building records identified the response mechanisms which were important during the 1979 earthquake. It was shown that, in the E-W, N-S, and torsional directions, changing modal behavior was evident. In all directions, the first two modes were amplified and apparent before and after significant changes in the responses occurred and soil-structure interaction was evident in both horizontal directions.

References

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HORIZONTAL ACCELEROMETER (H)
OR VERTICAL ACCELEROMETER (V).
TRACE NUMBER SHOWN IN CIRCLE.
ARROWS DENOTE DIRECTION OF
POSITIVE ACCELERATION.

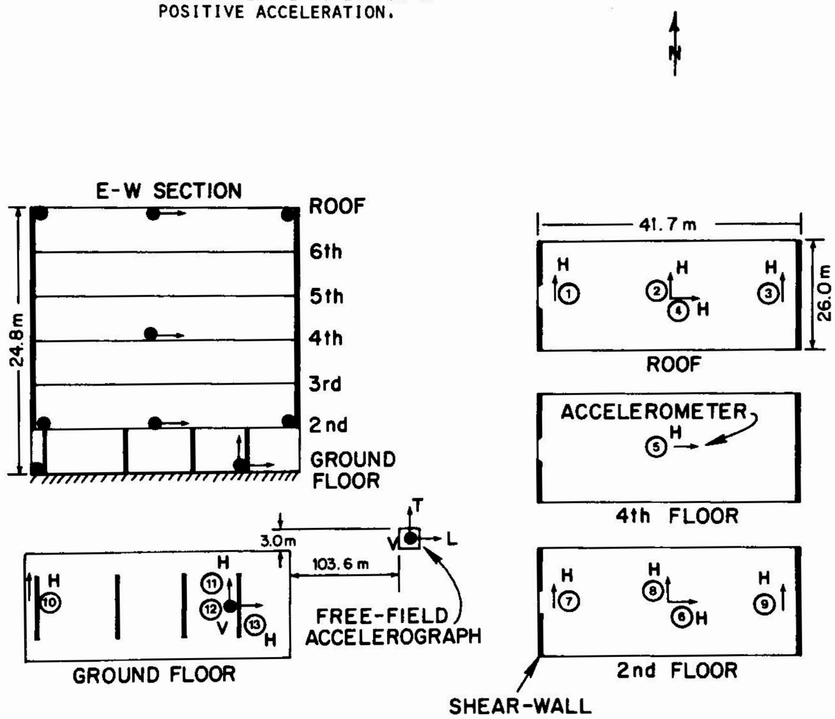

Figure 1 Building Configuration and Location of Strong Motion Instrumentation

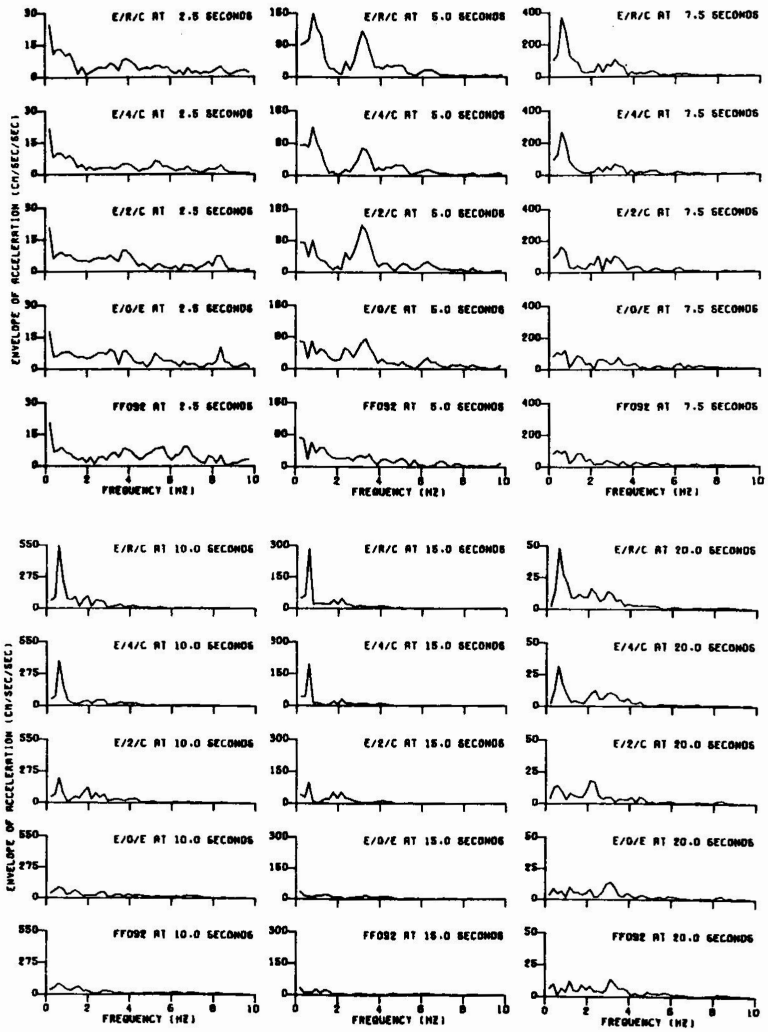

Figure 2 Time Variation of the Spectral Content in the E-W Direction

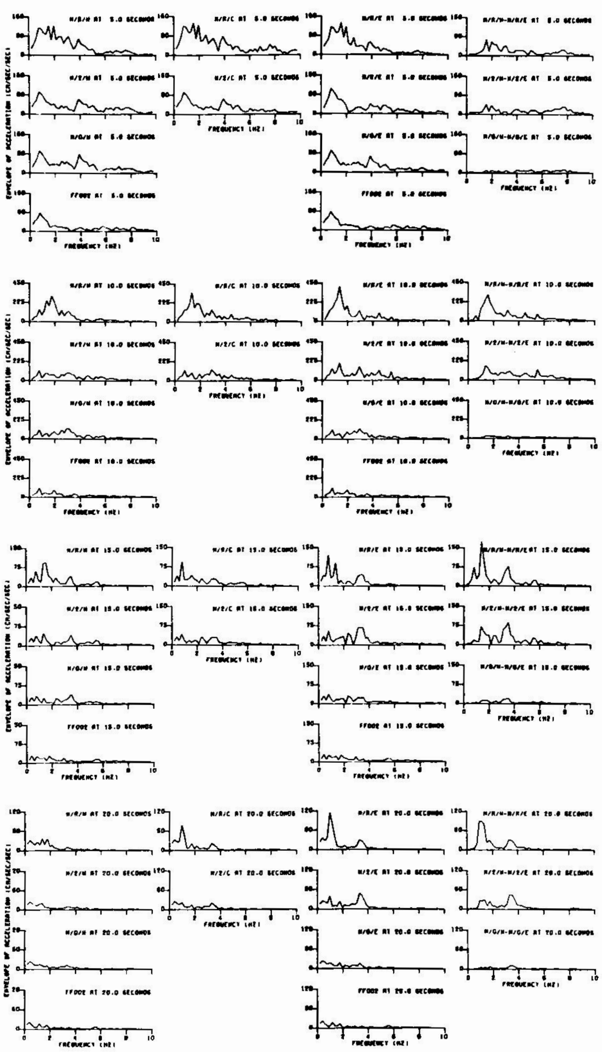

Figure 3 Time Variation of the Spectral Content in the N-S Direction

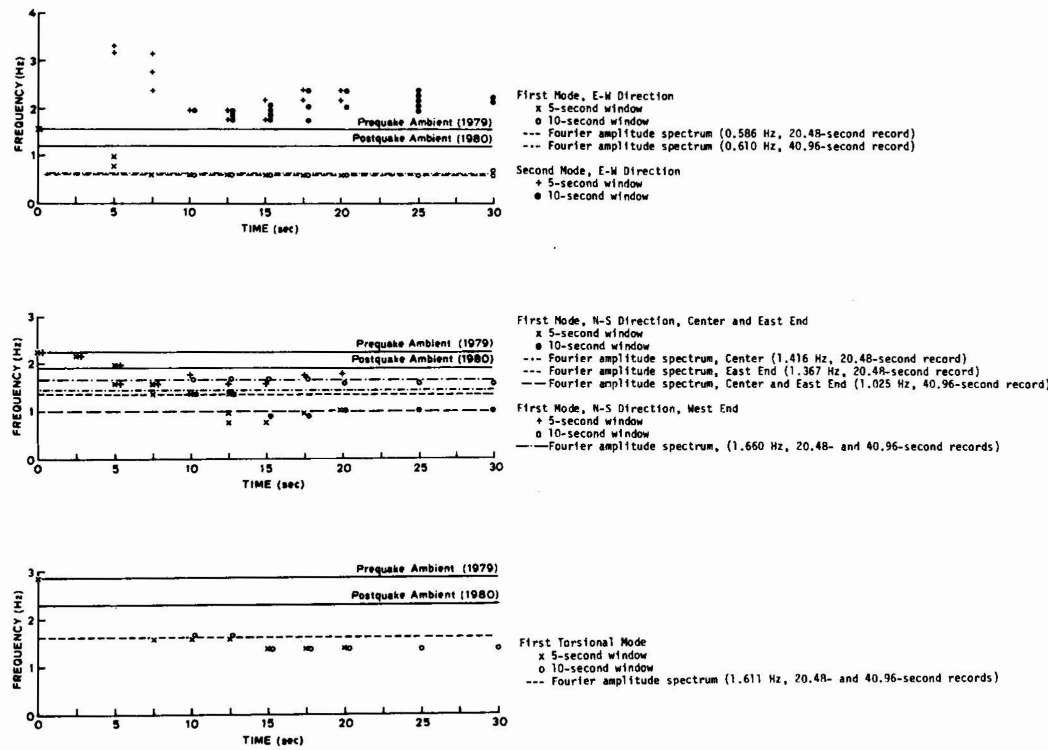

Figure 4 Time Variation of the Modal Responses in the E-W, N-S, and Torsional Directions

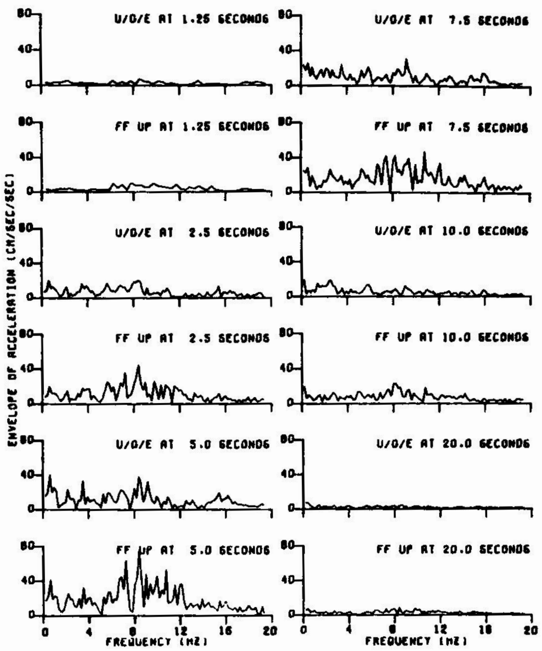

Figure 5 Time Variation of the Spectral Content in the Vertical Direction