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Recent developments in seismic isolation in New Zealand

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ABSTRACT: Three recent projects of very diverse nature required extensions to technologies for seismic isolation and energy absorption. The structures involved were a 10 storey building, capacitor stacks at an electrical substation, and a large printing press. All three projects were sited close to the Wellington fault which is capable of generating earthquakes up to magnitude 7.5. Response studies carried out for the three structures showed that the level of protection afforded to each by its chosen isolation system was greater than could be provided by conventional strength measures, and in one case a significant cost saving was realised. The isolation systems used to protect the printing press and the building were able to cope with seismic ground motions containing "fat-pulses" of the type present in the 1971 Pacoima Dam accelerogram. Samples of each energy absorbing device were tested, and in each case the measured performance compared well with extrapolation from previous test data.

1 INTRODUCTION

Three recent projects in New Zealand illustrate the capability of seismic isolation to provide added dimensions to the earthquake protection of structures and equipment. The projects were a new central police station in Wellington city, the retrofitting of seismic-isolation to capacitor stacks at an electricity supply substation 20 km north of Wellington city, and the protection of a large printing press at Petone 10 km north of Wellington city. All three projects were sited close to the Wellington fault, at distances of 1200 m, 800 m, and 20 m respectively, in New Zealand's most active seismic region. Two of the projects, the new police station and the capacitor stacks, involved facilities that were required to remain functional after a major earthquake, and two, the capacitor stacks and the printing press, involved brittle equipment that was highly vulnerable to earthquake attack and traditionally not protected from earthquakes.

2 DESIGN GROUND MOTIONS

The ground shaking specifications for the three projects were developed specifically for each project according to the knowledge then available. This was done in 1986 for the police station, 1988 for the capacitor stacks and 1989 for the printing press. The nearby Wellington fault is thought to be capable of generating $M_S = 7.5$ events at average intervals of 500-600 years, and so the specified ground motions were very strong.

The earthquake records used in the analyses were scaled to match the design spectra at the fundamental period of vibration of each isolated structure. This was 3.0 s for the police station and 2.0 s for the printing press. The police station was required to be operational after a 450 year return period event which had shaking equivalent to 1.4 x El Centro (NS) 1940, 3.2 x Taft (S69E) 1952, PGA = 0.60 g, and 0.64 x Pacoima (S14W) 1971. The printing press was designed for 2.0 x El Centro and 4.1 x Taft. It was also designed for 0.53 x Pacoima Dam (S14W) 1971, PGA = 0.62 g, this record containing fat pulses which cause high ductility demands (Dowrick *et al*, 1991). The capacitor stacks at the substation were designed for a 1000 year event having a PGA = 1.0 g and a spectral acceleration $S_a = 0.6$ g at T = 2.0 s.

3 WELLINGTON CENTRAL POLICE STATION

The police station has a 10 storey tower block above a separate basement (Figure 1). The tower block was isolated by supporting it on pin-ended piles separated from the ground by hollow sleeves, with horizontal displacement control in the form of lead extrusion dampers located at ground level and pinned between the base of the tower block and the basement. The reinforced concrete superstructure was stiffened by diagonal bracing. A detailed description of the isolation system and the structure has been given by Charleson

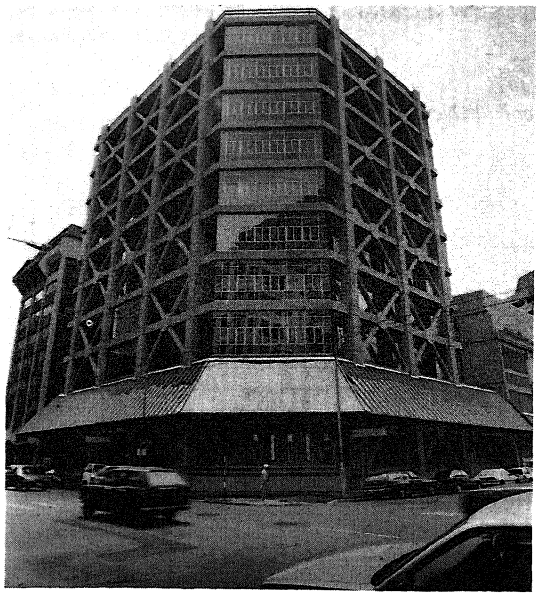

Figure 1: The Wellington Central Police station

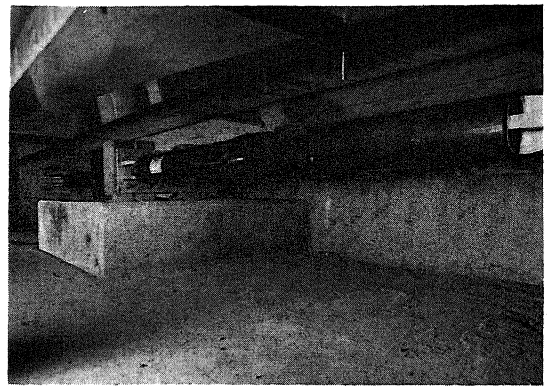

Figure 2: Three of the 250kN lead-extrusion dampers beneath the Wellington Central Police station. The outer ends of the dampers are pinned to columns of the isolated structure and the inner ends to a reaction block attached to the ground.

et al (1987), who noted that there was a saving of 10% in the structural cost associated with the seismic isolation option.

The calculated maximum horizontal displacement of the ground floor in the 1000 year return period excitations was 375 mm. Such a large displacement demand, together with the almost elasto-plastic response required from the energy dissipators led to the choice of lead-extrusion dampers. Six dampers, each rated at 250 kN force and $\pm$400 mm stroke, were mounted along each side of the tower block, so as to give a total damping force of 3000 kN, or 0.035 of the building's seismic weight, in each orthogonal direction (Figure 2).

Because the 250 kN damper was nearly twice as large as any previously manufactured, an extensive mechanical testing program was carried out. All manufactured dampers were subjected to 6 cycles of $\pm$250 mm displacement at 0.1 Hz at ambient temperature and one, a prototype, was similarly cycled at 0°C. The hysteretic behaviour of the 250 kN damper (Figure 3) was satisfactory and similar to that of the smaller dampers previously tested (Robinson & Greenbank, 1976; Robinson & Cousins, 1988). Apart from minor perturbations caused by the segmented nature of the lead core, the load remained steady

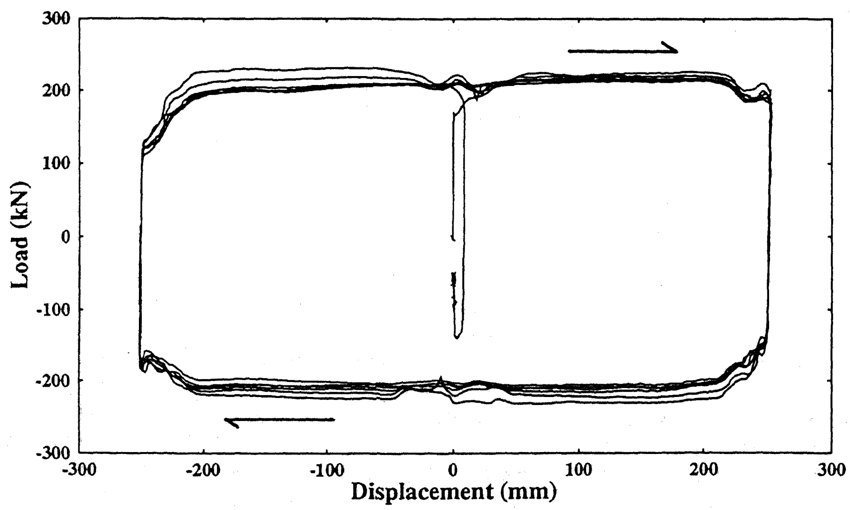

Figure 3: Hysteresis loops for a 250 kN lead-extrusion damper cycled at 0.1 Hz for 6 cycles.

between changes in the direction of displacement, and there was a continuing decrease in load and energy absorption with cycling as the lead in the damper was heated. The average energy absorption over the first three cycles was a little over 80% of the nominal energy absorption. Cooling to $0^{o}C$ made very little difference to either the shape or size of the hysteresis loops with the variation observed being no greater than the variation from test-to-test at constant temperature.

4 HAYWARDS SUBSTATION CAPACITOR STACKS

Electricity suppliers in New Zealand have started a process of selective retrofitting of seismic isolation to key items of highly vulnerable substation equipment. A recent example of this retrofitting is provided by the isolation of capacitor stacks at the Haywards substation, which is a major substation 20 km north of Wellington. A typical capacitor stack consisted of a group of capacitors with brittle ceramic insulators, mounted within a cross-braced steel cage measuring 9 m in length, 6 m in height, and 3.6 m in width. It weighed 26 tonnes and was supported on 8 ceramic insulators each 1.5 m high.

Seismic-isolation was achieved by raising the capacitor stack and its insulators approximately 1 m off the ground and inserting a horizontal steel frame that was supported on six laminated steel-rubber bearings. The relatively low mass of the capacitor stacks required a very low shear stiffness for the bearings, which therefore had to be made from rubber-encased steel plates separated from one another by small pads of rubber in order to give adequate stability (Tyler, 1991).

Damping was provided by two steel taper-beam dampers which were connected between the steel frame and the ground at each end of the capacitor stack. Specifications for the dampers were derived from dynamic analyses of the isolated structure. The main ones were: nominal damping force: 10.6 kN; displacement capacity: $\pm$ 200 mm; lifetime: > 70 cycles at full displacement; and directionality: omni-directional in horizontal plane. The total damping force required for each capacitor stack was approximately 10% of the structural weight. This was higher than normally used in seismic-isolation and was a consequence of the severe seismic design requirements.

A cylindrical type of taper-beam damper seemed most appropriate given the small damping force and the need for omni-directionality. The design procedure was as described by Tyler (1978a,b) and resulted in a 500 mm long device of base diameter 45 mm, tapered over the lower two-thirds of its length to a diameter of 31.5 mm (Figure 4). The peak strain level in the steel beam at full displacement was estimated to be 0.03 which implied a cycling lifetime in excess of 100 cycles (Tyler, 1978a).

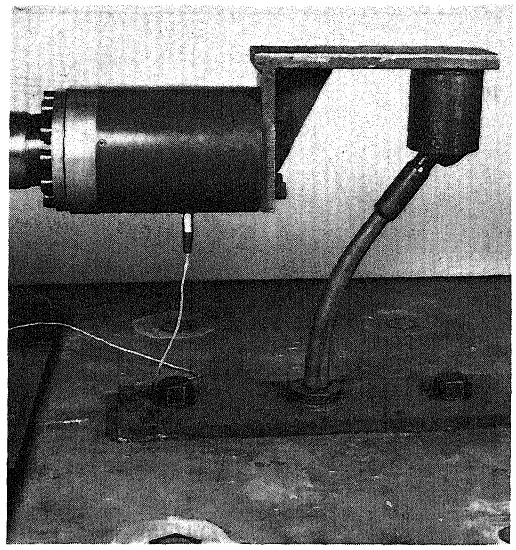

Figure 4: Steel taper-beam damper displaced to maximum stroke during testing.

This damper had a much smaller load capacity than those previously used in New Zealand and so cyclic load testing was required to firmly establish the mechanical performance characteristics. The resulting stable hysteretic behaviour with good energy dissipation from one series of tests (Cousins *et al*, 1991) is shown in Figure 5. Two dampers were tested and both met the specifications listed above.

5 WELLINGTON NEWSPAPERS LTD PRINTING PRESS

The printing press was made principally of cast-iron and was equivalent vertically to a four storey building. It was located in a building made principally of reinforced concrete with a structural steel roof. To provide maximum protection from earthquakes the building was especially stiffened up to a height of 8.6 m and was linked to the press with horizontal struts at heights of 4 and 8.6 m (Figure 6). Seismic isolation was achieved by providing lead-rubber bearings at the base (Dowrick *et al*, 1991).

In order to achieve the design displacement of $\pm$250 mm and damping force of 5 percent of structural weight, it was necessary to use bearings that were 609 mm square in plan, 460 mm high and fitted with 100 mm diameter lead plugs. The bearing height was about 50 percent greater than for any previously tested lead-rubber bearings, and so prototype testing of a pair of bearings was carried out to confirm their properties (Cousins *et al*, 1991). Their stable hysteretic behaviour

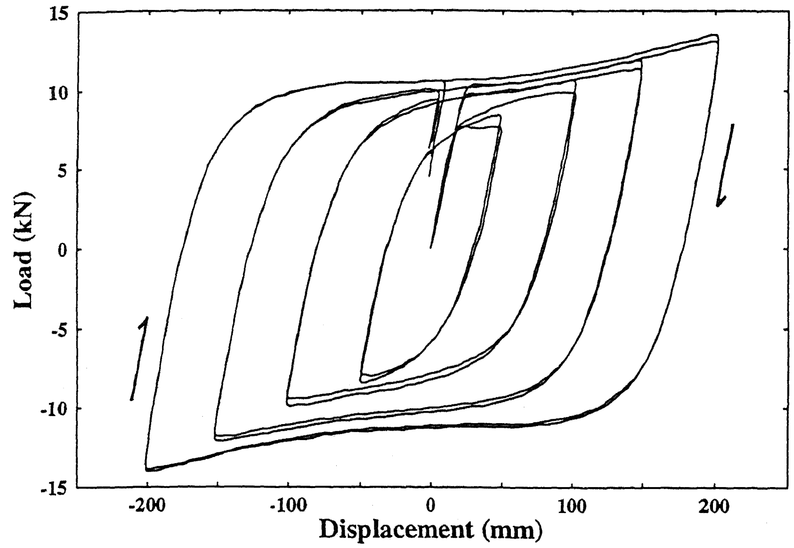

Figure 5: Family of load-displacement loops for a 10.6 kN steel taper-beam damper. The loops are from 2 cycle tests at displacement amplitudes of 50mm, 100mm, 150mm, and 200mm.

at a range of displacements is shown in Figure 7.

The hysteresis loops were similar in general form to those obtained previously for smaller lead-rubber bearings (Robinson 1982; Robinson & Cousins, 1988) although there was a tendency towards increased damping force as either the applied displacement or the axial load on the bearing were increased. The post-yield shear stiffness of a single bearing under large displacements was estimated to be 0.9 kN/mm which equals the shear stiffness of a similar laminated steel-rubber bearing without a lead core. The damping force for displacement amplitudes greater than 150 mm and axial loads of 1000 and 2600 kN was equivalent to a yield strength in shear for the lead plug of

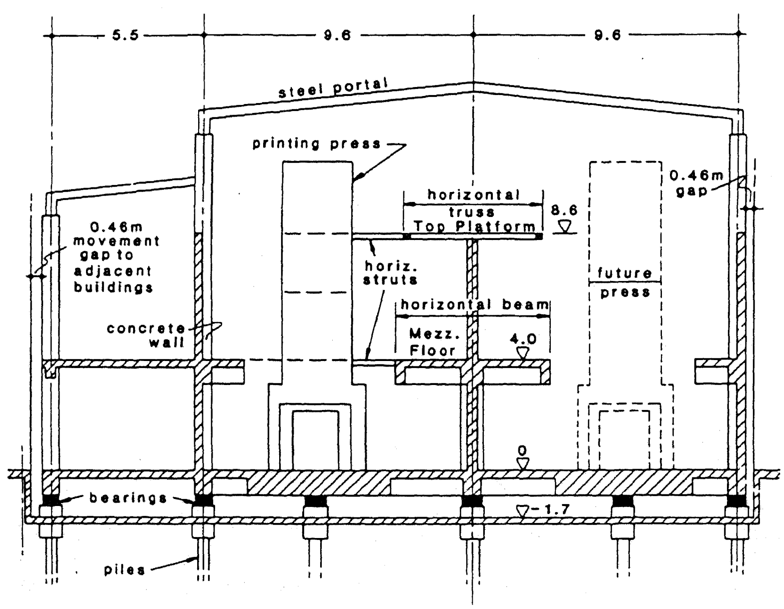

Figure 6: Cross sectional view of the printing press and its protective structures.

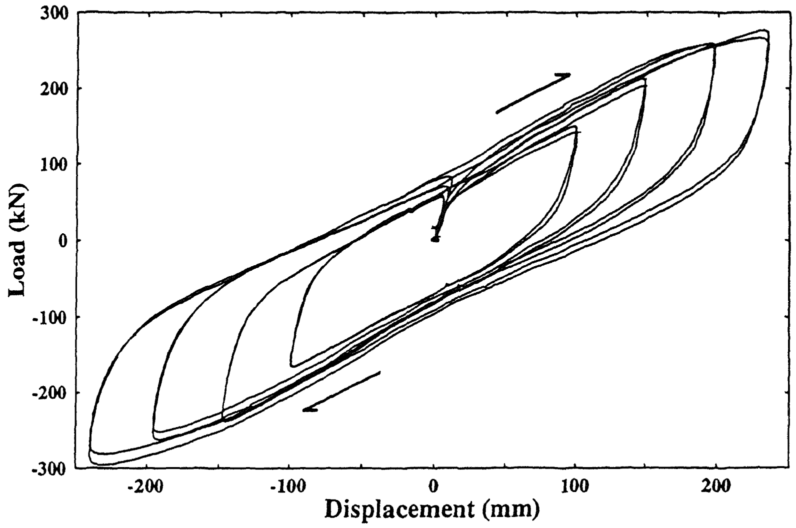

Figure 7: Family of load-displacement loops for a single lead-rubber bearing tested in cyclic shear. The loops are from 2 cycle tests at displacement amplitudes of 100mm, 150mm, 200mm, and 250mm, and the initial axial load was 2600 kN.

10.2-11.5 MPa, which compares well with 10.5 MPa, the yield strength in shear for high purity lead.

6 CONCLUSIONS

The energy dissipating devices adopted for these three projects each represented significant developments of the different devices concerned. The response studies carried out for the three structures showed that the level of protection afforded to each by its chosen isolation system was greater than could be provided by conventional strength measures, and in the case of a police station a significant cost saving was realised. It was also shown that the isolation system used to protect the printing press and the police station could cope with seismic ground motions containing "fat-pulses" of the type present in the 1971 Pacoima Dam accelerogram.

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