Base Isolation – development of the first test rig

(extracted in May 2011 from Cameron Smart‟s family history, "Baby Boomer – a life to be bettered‟, updated August 2014)

My superiors at PEL assigned me to a new project. During the late '60s the leader of the Engineering Seismology Section, Ivan Skinner, had conceived the idea of "base isolation" to defend buildings and bridges against earthquakes. The scheme was to have two foundations, one built into the ground in the usual manner, and another fixed to the bottom of the building. Between the two would be arrays of springs which would carry the weight but allow motion, and arrays of dampers which would absorb the energy of the motion. Ivan often used the phrase, "We want to give the building a soft ride." He had buildings of high value and high risk in mind, and mentioned hospitals and nuclear power stations. He had developed the mathematical theory, and technician Arnold Heine had experimentally developed small-scale dampers which absorbed energy by the plastic deformation of steel. Arnold had discovered that it was important to put the welds in places where they would not be subjected to the plasticity.

A real project then presented itself. New Zealand Railways were about to rebuild part of the North Island Main Trunk line near Taihape, and several long and high viaducts were needed. Ivan suggested a system of "stepping piers" for the longest and highest, using gravity as the spring and steel dampers to absorb the energy. He needed a machine to test the full-size dampers, and I was to design it!

My first thought was to acquire an old steam locomotive and use one of its cylinders and reciprocating parts to provide the necessary push-pull motion. This was not beyond the bounds of possibility, as the railways had only recently retired the last of its steam power, and I had a working relationship with some of the people at their Woburn workshops. Ivan had a better idea.

He had a working relationship with many of the senior engineers in Ministry of Works, and they could make an old Caterpillar D8 bulldozer from a quarry available to us. The deal was done for $1000, an area in one of the wooden sheds built by the US Marine Corps in 1942 was partially cleared for the machine, and I invited anyone who still had equipment there to move it or have it crushed. MoW [Ministry of Works] trucked the machine to Gracefield and unloaded it for us. The blade and tracks were of no use to our project, so I sold them for $1500, thereby overtaking Chief Electrical Engineer Dick Morris who had previously claimed the best commercial deal for the laboratory.

I decided to take the power from the left rear sprocket through an eccentric, using this as the first link in a 4-bar chain to change rotary to reciprocating motion. The eccentric was to take the form of one inside another, so that by rotating the inner with respect to the outer the stroke could be varied between tests. I did most of the detail drafting myself, and Ivan checked the drawings as they became available.

The eccentrics and connecting rod were to be made of spheroidal graphite cast iron, and I found some elderly patternmakers in Porirua to make the pattern equipment. The other parts were to be steel weldments: I made a 1/10 scale model of the reaction frame in thin sheet steel and took this to several fabricators, telling them I wanted one of these but ten times as big. William Cable's foundry in Gracefield and their fabricating shop in Kaiwharawhara proved to have the best combination of price and competence, so I awarded them the contacts.

In the neighbouring room in the old shed, the laboratory had erected a large photometer to make three-dimensional measurements of the light emitted by street lights and other powerful luminaires.

There was concern that engine vibrations would be transmitted through the concrete floor and damage the photometer. I knew a little about the theory of transmissibility of vibrations, and having done the necessary calculations and measured the properties of rubber sheets, designed mounting pads that required holes to be punched in the sheets to reduce their stiffness, and stacked several sheets on top of each other to further reduce the stiffness. Thus the vertical and horizontal stiffnesses were about equal. Each pad had sufficient footprint area to be stable.

I devised the title Masher – Machine for Simulating Earthquakes – as this was easily memorised and gave a good idea of its purpose. We could not afford a proper paint job, so we scrubbed off the worst of the dirt and flaking paint with wire brushes and brushed the Caterpillar parts yellow and the PEL parts orange, a colour scheme very popular in the 1970s. Ivan helped me with the painting, and later another technician with an artistic flair did the necessary signwriting on the back of the diesel tank.

Ivan had worked with NZR's chief bridge engineer GB Wilson on a proposal that required great A-frames to support the span. MoW had also proposed a design, but NZR thought this too expensive. NZR then put the job out for tender on a design-build basis. Beca Carter Hollings and Ferner formed a joint venture with the Italian company Codelfa-Codega with an H-frame design and the use of a launching span that had seen previous service on another viaduct. NZR then asked Beca to incorporate a stepping action into the design. Ivan helped with the stepping analysis and Masher was to be used to develop the energy-absorbing dampers[1].

While we at PEL were designing and building Masher, our colleagues at Beca were doing the detail design for the viaduct. Each of its reinforced concrete piers was to be built in the form of a capital H but with two crossbars. Earthquake components in the along-bridge direction would not be damped, but would be simply "toughed out" by longitudinal compression in the spans, resisted by the abutments on the banks of the river. Components in the cross-bridge direction would cause one leg of each pier to lift off its load-spreading rubber pad, and the span high above would be bent sideways elastically. Vertical actions would be resisted by both legs lifting together. The lift would be resisted by torsional plastic deformation of steel beams connected by spanner-like jaws to the foundation below and the bottom of the pier above. The active elements were about 750 mm long, 250 mm wide, and 50 mm thick. PEL welder Arthur Harris made these.

Laboratory Director Dr Mervyn Probine took a keen interest in the project. He had allowed a lot of money and time to be invested, and PEL's reputation was at stake. He had seen that the test piece was thicker than most of the parts in Masher. Would the test piece or the test rig yield first? A few days before the first test was scheduled he accosted me just inside the front door of the laboratory and physically forced me into a corner. How sure was I that it would all work? As Masher had never been driven in anger, I could not be sure at all. Not good enough! He commanded me very brusquely to have a prototype made only 25 mm thick, and the other dimensions the same. This was done.

The first test was scheduled for early one afternoon. A remarkable number of staff members decided they had business in that part of the old shed that afternoon, and gathered to watch. I poured petrol into the carburettor of the little starting engine and cranked this into life. I engaged its transmission and the big diesel started. Here was the moment of truth. I selected first gear, and let in the big final-drive clutch. The engine slowed momentarily, the mill scale on the 25 mm twisting beam cracked and fell off, surprising us all. Then the desired action occurred, the beam twisting back and forth as if it were made of plasticene. After a few cycles Ivan waved at me to stop,

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[1] Dr Richard Sharpe, Beca, private communication on the occasion of Ivan's funeral in August 2014.

which I did, and jumped down from the driver’s seat, grinning with pleasure and shaking at the knees.

Merv pushed through the crowd of spectators and asked me what I was going to do next. Risking my career, I told him I was going back to my office, which that day was in the beer garden of the Bellevue Hotel. He looked at me in some astonishment, and then said, “So am I. And I am buying the first drink!”

We drove our own cars to the Bellevue, and trooped in. At that time a Japanese seismologist had been working with Ivan, and he was one of the few staff members who had conscientiously attended to his own work and had not witnessed the test. “Where’s Dr Kittigawa?” Ivan asked. Realising he was not there, and knowing what a breach of hospitality protocol this was, Ivan jumped back into his car, made a tyre-screeching U-turn in front of the hotel, and raced back to the laboratory to fetch his honoured guest.

Merv did buy the first round of drinks, and allowed us to stay until mid-afternoon.

Masher gave very good service, and never let me down, not even during the numerous demonstrations we gave to visitors. Sometimes maintenance of the old Caterpillar machinery was required, but we always managed to do this before a scheduled test. On one occasion the transmission between the little petrol starting engine and the main diesel would not engage and the solution was not obvious. I rang Norm at breakfast time the next day to ask his advice. “What model D8 is it?” he asked. “It’s a 2U,” I replied. “That would be the worst of them,” was his less than encouraging reply, “but if we’ve still got a manual we’ll send it to yeh.” He almost always used the royal “we” but rarely pronounced “you” in the Received Standard style. A couple of days later the oil-stained manual arrived, and the repair procedure became obvious. I rang him that night to thank him. “How long did yeh take to do it?” he asked, a note of scorn quite discernible. “About 20 minutes,” I reported. “Cripes, that was all right then,” and his tone of voice told me that the standard time was an hour and he had expected us to take a day.

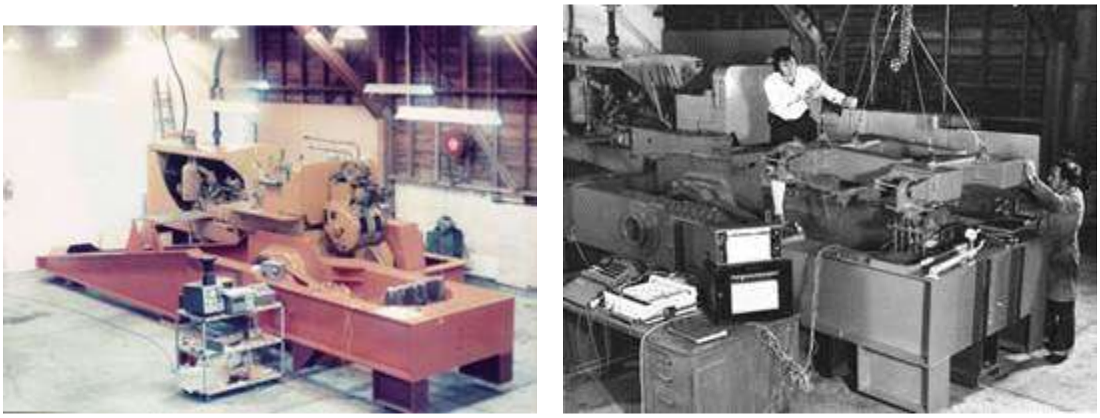

Figure 9: Masher when first built in 1974 for the twisting beam energy absorbers used in the South Rangitikei Viaduct, and being refitted in 1976 to develop the lead-rubber bearings. Sam Vanicek helps Cam (white shirt) to guide part of the test rig into place.

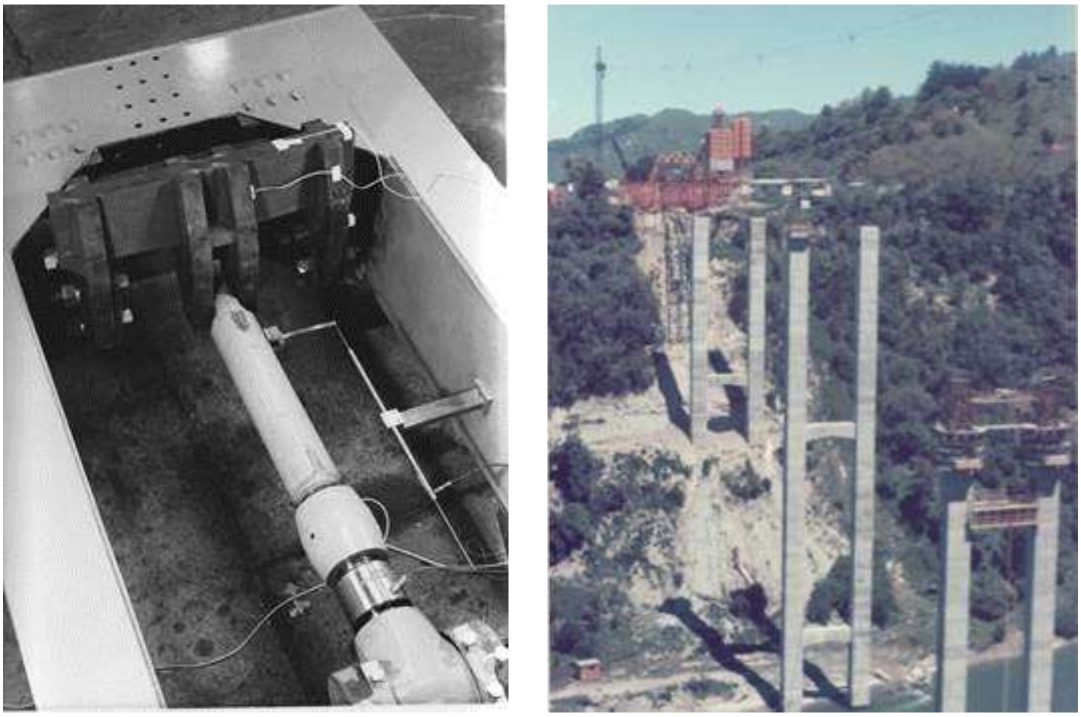

Figure 10: Left: Twisting beam earthquake energy absorber under test in Masher. We measured force with a strain gauge load cell, displacement with a linear voltage displacement transducer, and combined their analogue signals as hysteresis loops on an oscilloscope or paper chart recorder. Right: South Rangitikei Viaduct under construction.

We had to record the force and the displacement simultaneously, as these parameters and the energy absorbed in each cycle were needed for design. They all appeared together on hysteresis loops which we displayed on a cathode ray oscilloscope in early tests. Our initial practice was to photograph the loops with a Polaroid camera, and when the image rolled out of the camera, I would cut out the loop with scissors and weigh it. Comparison with the weight of a rectangle of scaled force and displacement gave us the energy represented by each loop.

In later tests we recorded the loops on a paper chart recorder, and then manually digitised them by following the lines with a mouse-like cursor on a digitising tablet.