Field Testing of a Soft-Storey Building in Melbourne

Rupali S Bhamare[1], Ari Wibowo[2], Emad F Gad[1, 2], Philip Collier[3], John L Wilson[2], Nelson T K Lam[1], Kittipom Rodsin [4]

1. Dept of Civil and Environmental Engineering, The University of Melbourne, VIC. 3010, Australia.
2. Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Hawthorn, VIC. 3122, Australia.
3. Dept of Geomatics, The University of Melbourne, VIC. 3010, Australia.
4. King Monghut's University of Technology, North Bangkok, Thailand.

ABSTRACT:

Building structures possessing vertical stiffness irregularity with an open ground storey are common in areas of low and moderate seismicity. These types of structures translate back and forth like an inverted pendulum during earthquake shaking, with the columns in the open storey often susceptible to severe damage and collapse.

This paper presents an overview of a collaborative research project which has been undertaken by Swinburne University of Technology and The University of Melbourne, Australia. The paper presents outcomes of unique experimental field testing on a four-storey soft storey building in Melbourne. The major aim of the project is to study the load deflection behaviour of soft storey buildings when subjected to lateral loading and to assess the lateral load and drift capacity. The results from the field test will be used to develop a representative seismic performance assessment procedure for soft storey buildings subject to different levels of ground shaking using force and displacement principles.

KEYWORDS:

Field testing, earthquake response, displacement controlled behaviour, soft storey structures.

1. INTRODUCTION

1.1. Background

Multi-storey buildings are becoming increasingly common in developed and developing countries with the increase in urbanization all over the world. Many of these buildings do not have structural walls at ground floor level to increase the flexibility of the space for recreational use, parking or for retail or commercial use. These buildings which possess storeys that are significantly weaker or more flexible than adjacent storeys are known as soft storey buildings. Under significant ground shaking these structures behave like an inverted pendulum (Figure 1) with deformations and damage concentrated at the soft storey and the columns which must resist the full axial gravity loading also being forced to deform laterally. These structures as a result tend to have limited displacement capacity and vulnerable to severe ground shaking when the displacement demand can be very significant. Although such buildings tend to be banned in regions of high seismicity, soft storey buildings tend to be common in regions of low to moderate seismicity such as Australia.

1.2. Scope and Objective

A research project has been undertaken by Swinburne University of Technology in collaboration with The University of Melbourne, Australia which involves experimental field testing of a four-storey soft storey building in Melbourne. The major aim of this unique project is to study the load deflection behaviour of soft storey buildings when subjected to lateral loading. The results from the field test will be used to develop a representative seismic performance assessment procedure for soft storey buildings subject to different levels of ground shaking.

This paper provides an overview of the experimental field testing of the soft storey building. Details of the building configuration and experimental test set-up, instrumentation and test results are provided in Sections 2, 3, and 4 respectively. In addition, the results from a vibration test on the whole building to evaluate the dynamic properties are summarized in Section 5.

2. BUILDING CONFIGURATION AND TEST SET-UP

The configuration of the buildings are shown in Figures 2 and 3 and consisted of four levels above the open plan ground storey. The upper levels were constructed from precast concrete wall panels and floors whilst the ground floor consisted of reinforced concrete columns and beams founded on individual pad footings. The building is significantly stronger in the short portal direction compared with the long spandrel direction. The Office of Housing in Victoria has a large number of such buildings known a ‘walk up flats’ in their portfolio and all constructed in the 1960s. Some of the ground floors of these buildings were constructed insitu whilst some of the later stock was constructed using precast columns and beams. Observations from the earlier demolition of adjacent buildings indicated that the building to be used for the experimental testing had a precast ground floor storey (Figures 4 and 5) with connections significantly weaker than the members they connect as detailed in Figure 7.

Four push-over field tests were undertaken on a ground floor bay consisting of four columns pre-loaded with kentledge. It was decided for safety reasons to demolish the upper levels of the building to first floor level to create the test specimens as shown in Figure 6. A steel frame was constructed at first floor level and positively secured to the slab and beams to provide support for the kentledge and to provide anchorage for the lateral load to be applied to the soft storey bay. Horizontal loads were applied in both the strong and weak directions via steel tension ties and hydraulic jacks secured to a piled tie back system some distance from the frames as shown schematically in Figure 8. The four columns in a typical bay would need to support around 200 tonnes of dead load plus a proportion of live load from the upper storeys, however it was not deemed practical to load the frame with the full gravity load and consequently 50 tonnes of kentledge in the form of precast 'jersy barriers' was added to provide a reasonable loading as shown in Figure 9. Interestingly, the slab on ground provided significant restraint to the columns at ground floor level and consequently two tests were conducted with the ground slab intact and the other two tests with the slab cut away to prevent restraint. The subsequent four field tests consisted of:

Test 1: Strong direction with ground slab

Test 2: Weak direction with ground slab

Test 3: Strong direction without ground slab

Test 4: Weak direction without ground slab

Due to space constraints this paper will focus on the results from Test 4 only.

3. INSTRUMENTATION

Various measurement techniques were utilised to obtain the overall load deflection behaviour of each test specimen as well as curvature of the column and crack width. The loads were measured using load cells, whilst the displacement measurement techniques included; GPS, total point station (TPS), visual measurement using a theodolite and ruler, LVDT transducers, laser scanner and photogrammetry. A degree of redundancy was built into the measuring systems to ensure that if one system failed, results could be obtained from other sources. In addition, some systems provided real time readings such as visual measurement and LVDT whilst other methods such as photogrammetry and laser scanner required some post processing. The main measuring systems are described in the following subsections.

3.1. Global Positioning System (GPS)

The GPS was used to continuously record the 3D movement of the structure with respect to time. Three GPS antennas were mounted on prefabricated masts located on top of the test bay that allowed the antennas to be elevated above the height of the kentledge as shown in Figure

9a. The accuracy of the GPS readings was about ± 2-3mm and ± 5-6mm for horizontal and vertical measurements respectively. Measurements were recorded at a frequency 20Hz. The position of the antennas on the structure were determined relatively to a nearby reference station located on stable ground, as shown in Figure 9b.

3.2. Total Point Station (TPS)

An electronic total point station (Figure 10a) was also used for determining the 3D movements of number of discrete target points on the structure. The target points had been glued onto the column and beam at specific locations. The location of the target points are shown in Figure 10b and were surveyed at regular intervals to determine the displacements at nominated load increments. The accuracy of the total station was about ± 2mm in 3D.

3.3. Laser Scanner

A laser scanner was used to obtain 3D determinations of the overall structural movement. The laser scanner recorded displacement measurements across the entire structure at a grid spacing of (5mm x 5mm) with an accuracy of about ± 2-4mm. The laser scanner effectively produces a 3D model of the structure and allows inter-comparison of subsequent scans to determine relative displacement between load increments.

3.4. Photogrammetry

The photogrammetry provided deformation data with an accuracy of about ± 0.05mm for each target location that were strategically placed to obtain information about the deformation of the elements and connections. The photogrammetry technique utilises a high resolution digital SLR camera, scale bar, a network of retro-reflective targets and sophisticated software to interpret the data. Photographs of the targets are taken before and after an event and the relative changes to the 3D position of the targets is calculated using the principles of triangulation from which average surface strains can be estimated.

3.5. Theodolite and Visual Displacement Measurement

Simple scale rulers were glued to the top of the test bay to directly measure the displacement using a theodolite as shown in Figure11. These measurements were particularly important for controlling the applied incremental displacements when the testing was in ‘displacement’ control. This proved to be a very accurate way of measuring the displacement in the direction of applied load and gave real time results by which the load increment could be controlled.

4. TEST PROCEDURE AND EXPERIMENTAL RESULTS

4.1. Test Procedure

A hydraulic jacking system with tension ties and a temporary piled tie back anchorage system were used to apply the lateral loads to the frame as shown in Figure 12. The test specimen was laterally loaded under ‘force’ control with load increments of 10KN until the ultimate load was reached followed by ‘displacement’ control with displacement increments of 25mm up to around 250mm in each direction.

4.2. Experimental Results

A comprehensive set of results have been obtained from the experimental testing and a sample load displacement curve for Test 4 is shown in Figure13. The displacement shown corresponds to the lateral displacement at the slab level and the load is the total lateral force imposed on the structure. The soft storey column was found to have significant displacement capacity irrespective of strength degradation. An important outcome of this work is that the columns maintained their gravity load carrying capacity at a lateral displacement of about 260mm or a drift capacity of about 8% under these quasi-static conditions. Interestingly, the weak column/foundation and column/beam precast connections allowed the columns to rock about their ends, greatly enhancing the displacement capacity of the soft storey system compared with rigid end column connections more typical of in-situ construction.

5. VIBRATION TEST

The basic dynamic parameters of the whole building were evaluated by performing a vibration test prior to the actual demolition work. Accelerometers were placed at two corners of the building and the structure was excited manually in lieu of ambient vibrations, due to the lack of wind at the time of testing. Modal parameters were evaluated using a classical frequency domain approach with ARTeMIS software to identify the natural frequencies and mode shapes. The experimental results compared favorably with the approximate Code predictions as summarized in Table 1.

Table1: Modal parameters

Modes	ARTeMIS results	Theoretical Prediction		
		AS1170.4 (1993)	AS1170.4 (2007)	UBC
Mode 1: Sway in weak direction	2.2 Hz	hn/46 = 3.23Hz	$T= 1.25(k_t)(h_n)^{0.75}$ = 0..442sec f = 2.26Hz	f=10/n f=2 Hz
Mode 2: Sway in strong direction	2.6 Hz	hn/58 = 4.07Hz		
Mode 3: Torsion	3.1 Hz	-		

hn=storey height; kt=0.05; UBC: Uniform Building Code; n= number of storey

6. CLOSING REMARK

This paper describes a unique field testing program using a soft storey building in the process of demolition. Four test bays were tested in the strong and weak directions to obtain an actual push-over force-displacement curve. Comprehensive deformation measurements were collected using GPS, laser scanner, total station, theodolites, LVDT and photogrammetry techniques. The preliminary results showed that the soft storey columns could sustain the gravity axial loads over a large lateral displacement of about 8% drift under rocking action. Analyses are currently being undertaken on all the bays tested to compare the experimental and theoretical results. In addition the experimental results are being used to predict the performance of soft storey buildings when subjected to different earthquakes and compare that with current code recommendations.

7. ACKNOWLEDGEMENT

The active support in completing field test from Delta Demolitions, the Office of Housing, and Fenton Partners, is gratefully appreciated. The authors are also very grateful to David Heath of The Department of Civil And Environmental Engineering, Melbourne University for his assistance with the photogrammetry measurements and Eldar Rubinov and Anna Donets of The Department of Geomatics, Melbourne University for their assistance with the GPS, total station and laser scanner measurements.

8. REFERENCES

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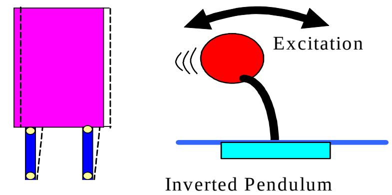


Figure 1: Idealisation of soft storey structures.

Figure 2: Photos of test building.

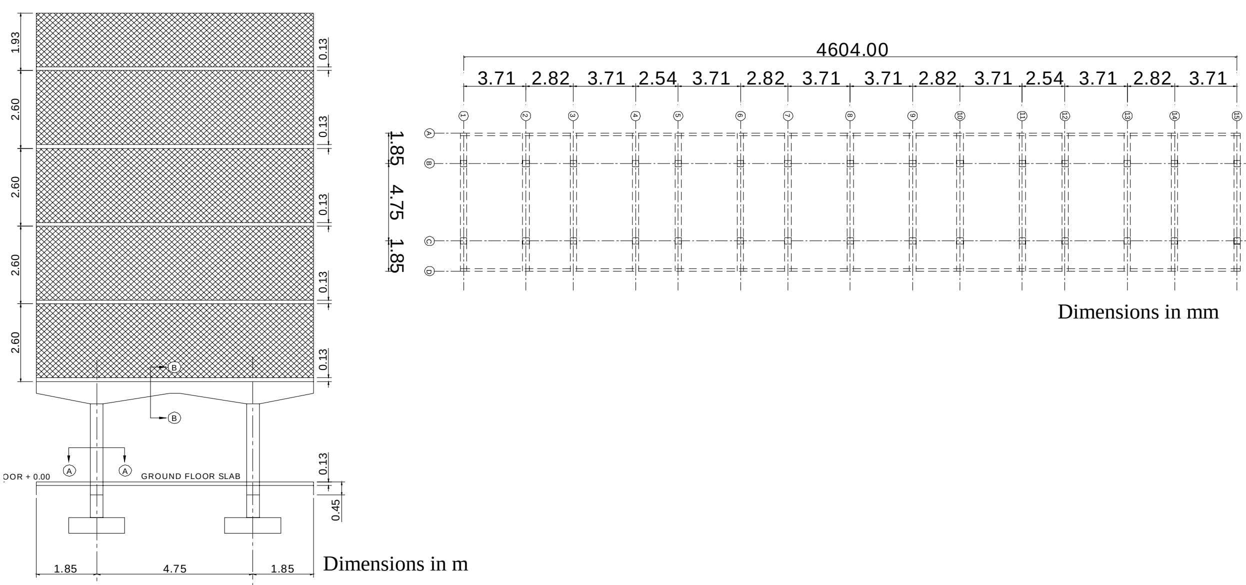


Figure 3: Elevation and plan of the test building.

(a) (b) (c)

Figure 4: Pretrial testing.

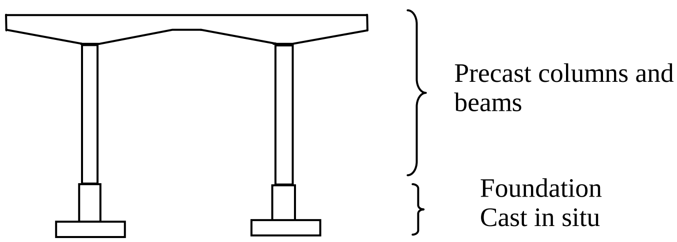


Figure 5: Constructional details of the building frame.

Figure 6: Preparation of test specimen.

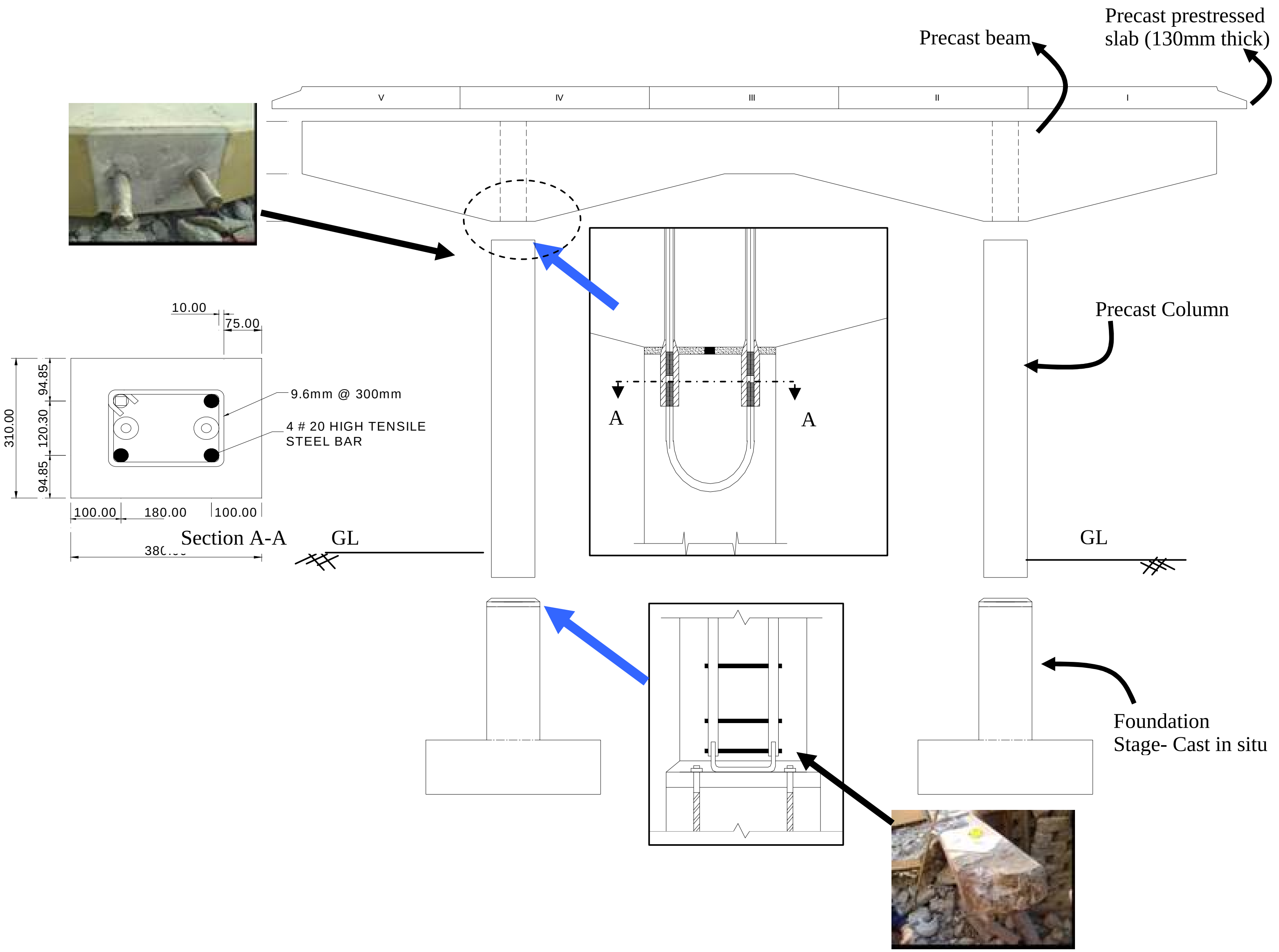
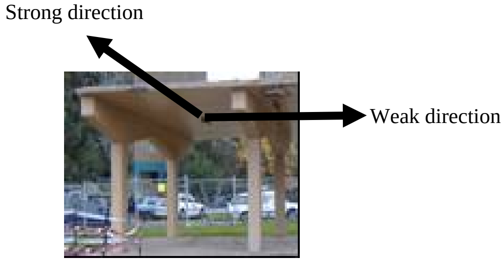
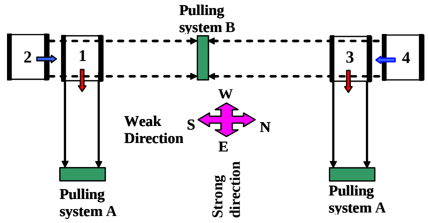


Figure 7: Structural details of a test frame.

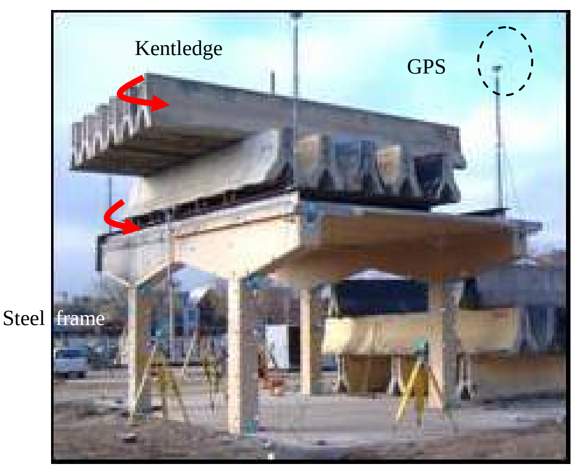


(a)

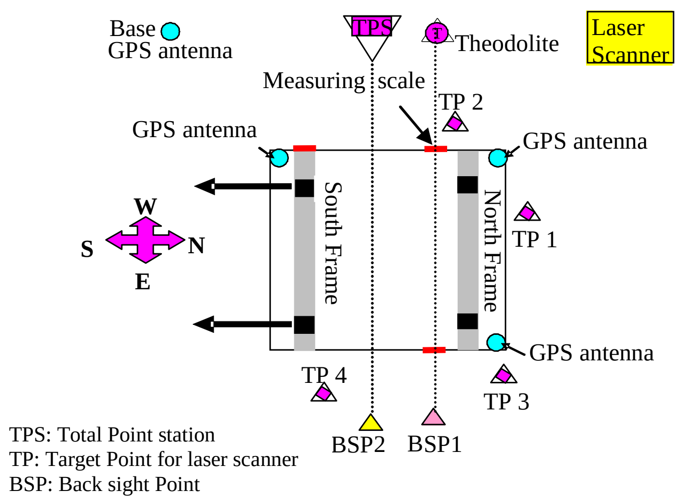


(b)

Figure 8: Test arrangements:
(a) A typical test bay (b) Plan view of the 4 test bays and direction of testing.



(a)



(b)

Figure 9: Setup for Test 4
(a) test set up (b) test set up in plan.

(a) (b) (c)

Figure 10: Instrumentation
(a) Total point station unit (b) Target locations for TPS (c) Laser Scanner.

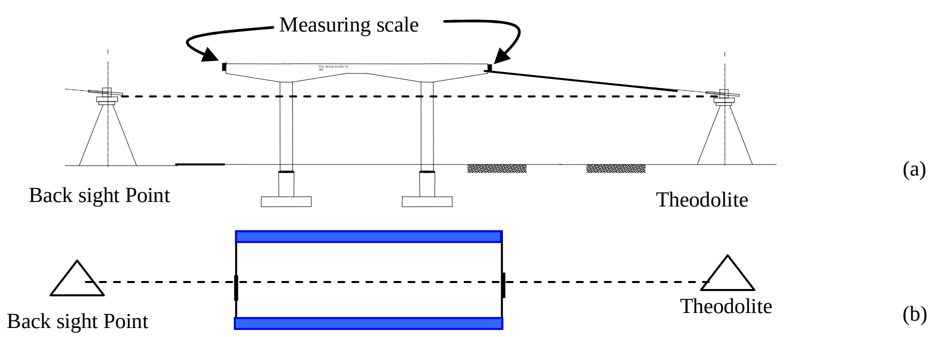


Figure 11: Lay out for visual measurements using the theodolite
(a) side view (b) plan.

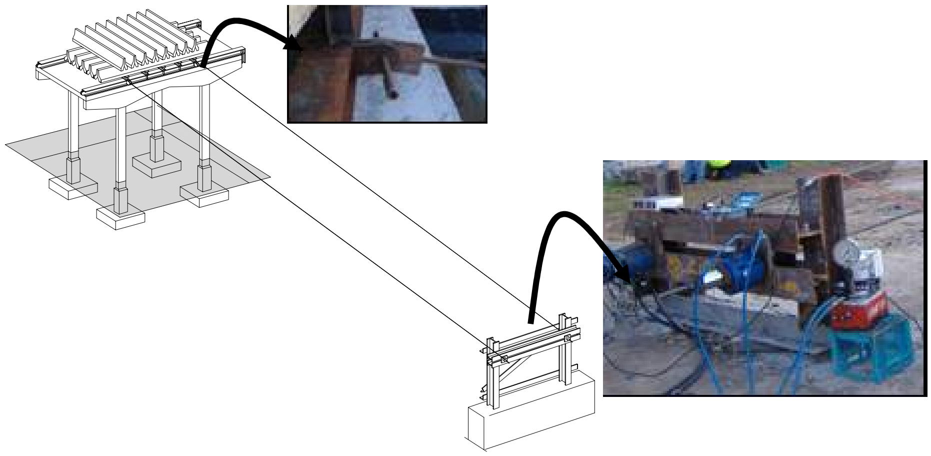
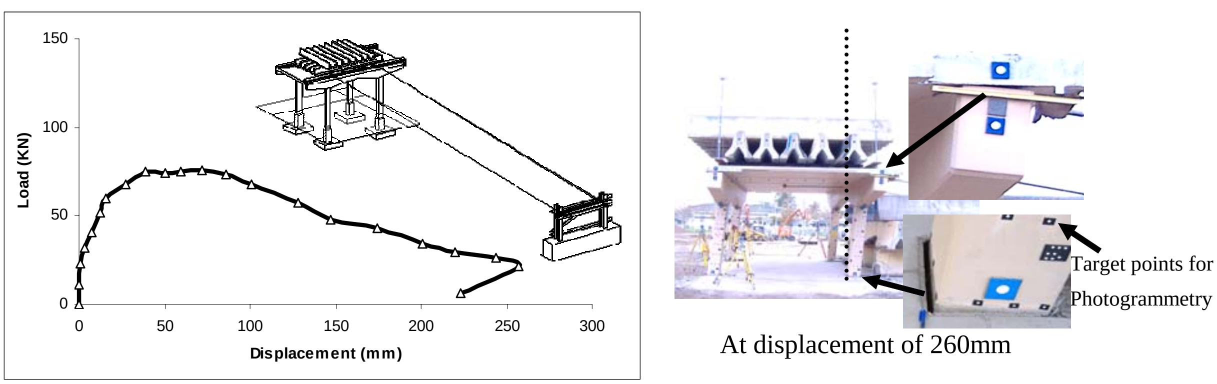


Figure 12: Test set up.



(a) (b)

Figure 13: Results for Test 4
(a) Load displacement curve (b) Overall deformations at 260mm displacement.