# Performance of a Reinforced Soil Wall in Sydney, Australia

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ABSTRACT: As part of the improvements to a grade separated interchange, six 8 m high Websol (or Freyssisol) walls were constructed in Western Sydney. The performance of one of these walls was monitored. This work involved a precision survey of panel movements, vertical earth pressure cells, bar extensometers to record movements within the clay shale backfill, and vibrating wire load bolts attached to the reinforcing strips. In addition, the dynamic response of the wall was evaluated. The average panel displacement was in the order of 50 mm. Base pressures indicated a load eccentricity during construction. Maximum strip tensions were some 40% below design values. Vibration measurements showed a dominant frequency of about 16 Hz, a shear modulus of 470 MPa (at a strain level of $9 \times 10^{-4}$%) and a damping ratio of 4%.

## 1 INTRODUCTION

The James Ruse Drive/Victoria Road Overpass is located in western Sydney. While the bridge deck itself is founded on piles, the two abutments and ramps were constructed using the Websol/Freyssisol soil reinforcing technique. The walls rise to a maximum height of 8.4 m. Maximum width of the reinforced soil blocks is 6.35 m. Grade 20, 30 and 50 Websol strips at a vertical spacing of 750 mm were used, ranging in length from 4 m at the bottom to 5.4 m at the top.

A total of six walls were constructed with a combined face area of 2400 $m^2$. The length of the ramps were 130 m. Construction commenced in March 1993 and took ten months to complete.

The James Ruse Drive walls were the first major structures with geosynthetic strip reinforcement built by the Road and Traffic Authority of New South Wales. Because of this and the fact that clayey shale was used as backfill, it was decided to make a detailed evaluation of the performance of the wall during and after construction. As illustrated in Fig. 1 the instrumentation involved the following:

- Four survey marks on each of the 16 panels shown on Fig. 1 to record their movements in three dimensions.
- Four pressure cells at the base of the wall for assessing the distribution of vertical stresses.
- Bar extensometers at two levels, measuring displacements within the reinforced soil (at about 1/3 and 2/3 heights). At these levels the strip lengths are 4.75 m and 5.4 m.
- Load bolt arrangements to monitor the tensions along one of the 4 m long Websol strips attached to the upper half of Panel 586 (Fig. 1). These load bolts consisted of vibrating wire cells (capacity 20 kN) clamped onto the strips in such a way that the reinforcing strips were not cut but looped around the measuring cell.

In addition, the dynamic response of the wall was tested, using a 5 tonne articulated vibrating roller as a source of excitation. The measured data were used for determining the natural frequencies, shear modulus, damping ratio and attenuation curves.

## 2 MATERIAL PROPERTIES

### 2.1 Backfill

The backfill material in the test section was a dark grey clayey shale consisting of gravel and sand sized shale fragments with a fines content of 4%. It had a liquid limit of 23% and a plasticity index of 8. When remoulded and compacted, this material behaved like a clay.

Field compaction aimed to obtain the standard maximum dry density of 2.02 $t/m^3$ (or 19.8 $kN/m^3$) at the optimum water content of 10.6%.

Direct shear test results are given in Table 1. The internal friction angle $\phi$ of the compacted and consolidated unsaturated soil was in the range of 41 to 44 degrees. When the compacted shale was saturated, the friction angle reduced to 29 degrees. However, since the walls are supporting the ramps of an overpass, complete saturation of the structure is not considered in the design.

### 2.2 Reinforcement

The reinforcement consists of strips made up of polyester fibres encased in a polyethylene sheath. This product has previously been known as Paraweb. The earth retaining system using these strips was originally called Websol, but is now marketed in Australia as Freyssisol.

The fill/reinforcement friction angle δ was measured in a direct shear test as 28.5 degrees. The ratio of the soil/reinforcement friction angle over internal friction angle, the δ/ϕ ratio, is then calculated as 0.67, for unsaturated conditions.

Table 1 Peak shear strength parameters

| Test material | Standard tests Peak values | |
|---|---|---|
| | c or $c_a$ (kPa) | ϕ or δ (°) |
| Fill, unsaturated | 96-128 | 41.2-44.3 |
| Fill, saturated | 38 | 29.2 |
| Fill/reinforcement unsaturated | 8 | 28.5 |

## 3 WALL DEFORMATION AND STRESSES

### 3.1 Lateral movement and distortion

Fig. 1 illustrates the outward movement of the wall panels since the start of construction (March 1993) to the present (April 1994). The wall movements are shown in form of a contour map. One of the wall panels (No. 662) has moved up to 100 mm. Most of the other surveyed panels typically showed less 50 mm deflection. The reason for one panel to move considerably more than others is a matter of speculation, but it seems to be related to

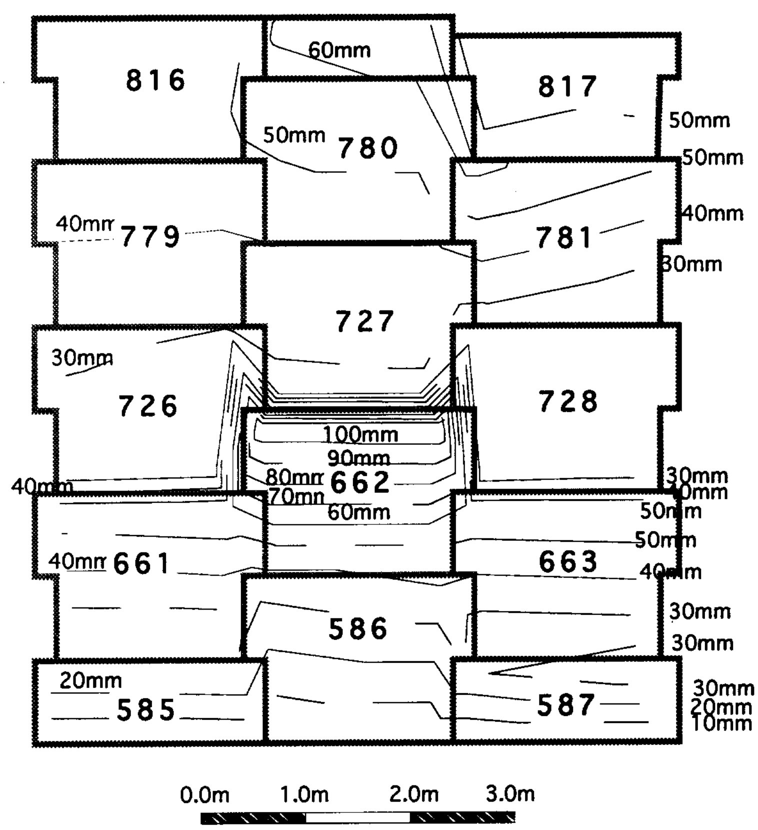


Fig. 1 Contours of lateral movement of panels

construction procedures.

Fig. 2 shows the internal movement of the reinforced fill behind Panel 662. Measurable lateral expansion of the fill occurred to a distance of about 5 m from the face panels. See Fig. 4 for wall heights corresponding to the monitoring dates.

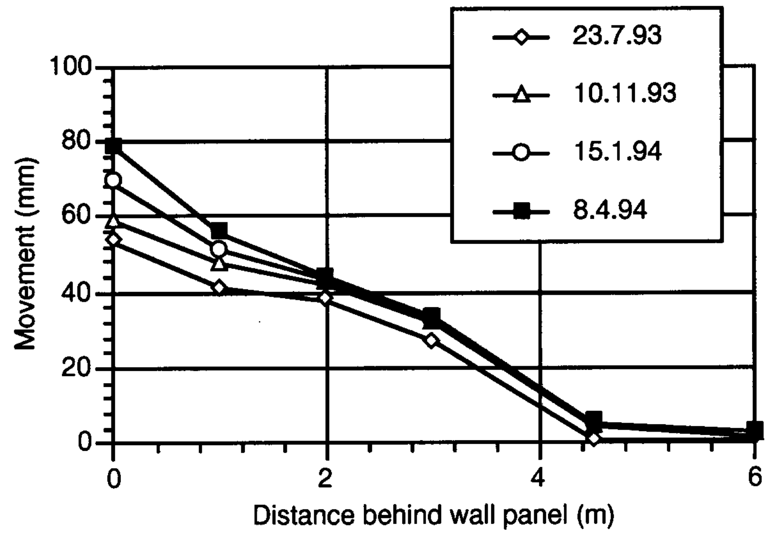


Fig. 2 Rod extensometer movements (behind Panel 662)

### 3.2 Reinforcement tension

An example of the measured strip tensions is plotted in Figure 3. A maximum tension of 4.1 kN occurred 1.5 m behind the face panel. The coherent gravity method of analysis predicted a tension of 10 kN/strip (neglecting the effect of cohesion). Maximum design capacity for a Grade 50 Websol strip is 19.3 kN. Brady (1987) also reported measured strip tensions considerably less than design values.

The low tensions recorded could be due either to some slippage of the straps in the measuring clamps or an anchorage effect by the clamps within the soil. The high cohesion of the clayey shale could also have contributed to lower than expected tensions, despite the obvious movement of the backfill.

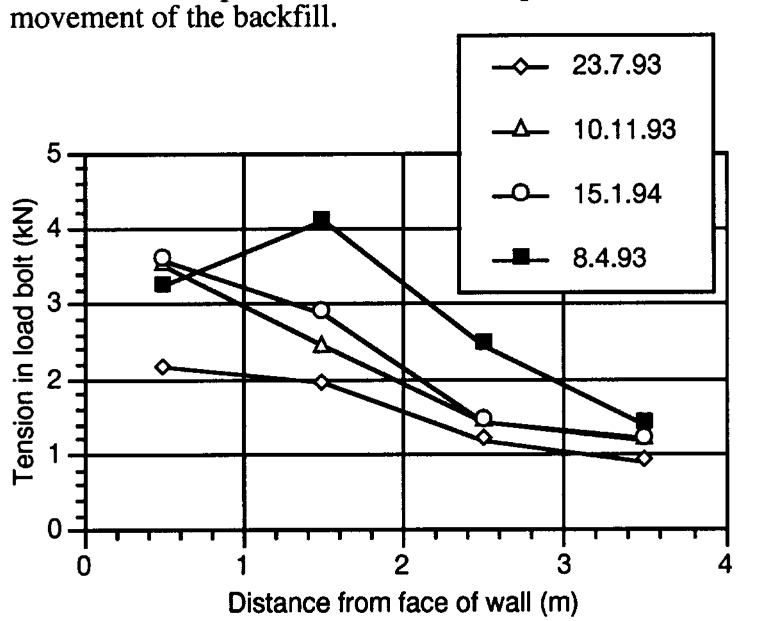


Fig. 3 Tensions measured along Websol strip

### 3.3 Vertical pressures

The earth pressure cells placed horizontally at the base of the wall did initially indicate eccentric loading at the base, typical for the tilting action of a retaining wall (Fig. 4). Vertical earth pressure after completion of the structure changed to a more uniform distribution. Calculated maximum bearing stress (after Meyerhof) is 205 kPa, assuming a traffic surcharge of 12.5 kPa. This compares with recorded values of 180 to 200 kPa.

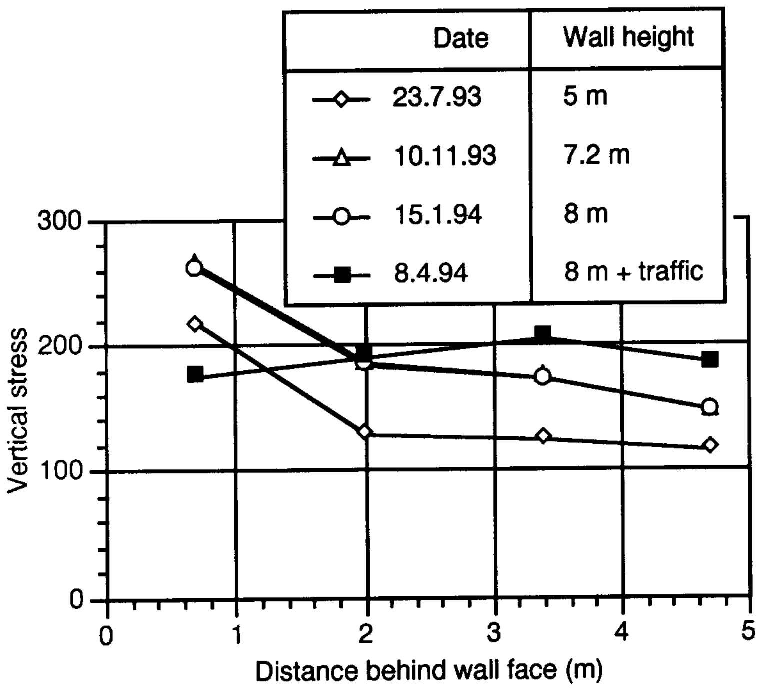


Fig. 4 Vertical pressures measured at base of wall

## 4 DYNAMIC RESPONSE

### 4.1 Testing procedure

The vibrations that were generated by the 5 tonne roller were measured at four points on a vertical line on the face near the instrumented wall section. The vibrations were measured simultaneously in horizontal direction (perpendicular to the wall) and in vertical direction. The positioning of the accelerometers on the wall is shown in Figure 5. The accelerometers were of type PCB Model 393C, with a range of $\pm 24.5$ m/s$^2$ and a resolution 0.001 m/s$^2$. The frequency range of the accelerometers was from 0.5 to 800 Hz. The analog signals from the accelerometers were transferred to the two analysing recorders (Yokogawa AR 1100). The recorders digitised the signals, converted them from voltage into acceleration, and stored them on a computer disk. On each measurement point there were two accelerometers, one in the horizontal direction, perpendicular to the surface of the wall, and one in the vertical direction. Additionally, one accelerometer was attached to the drum of the Roller in order to measure the vertical vibrations generated by the Roller.

The Roller was positioned at seven different locations (Fig. 6). Forced steady state vibrations were measured while the Roller was running.

The free vibrations were measured immediately after the machine was turned off. For this case the Roller was positioned at location 1, as shown in Figure 6.

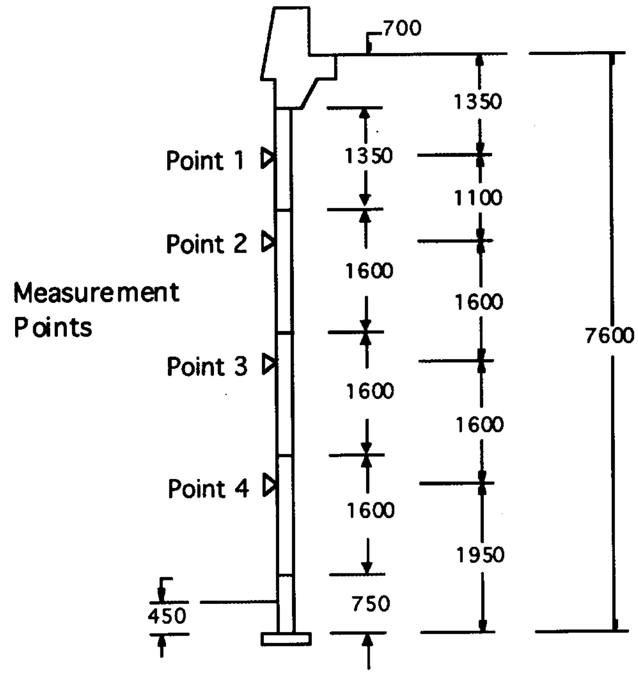


Fig. 5 Location of accelerometers

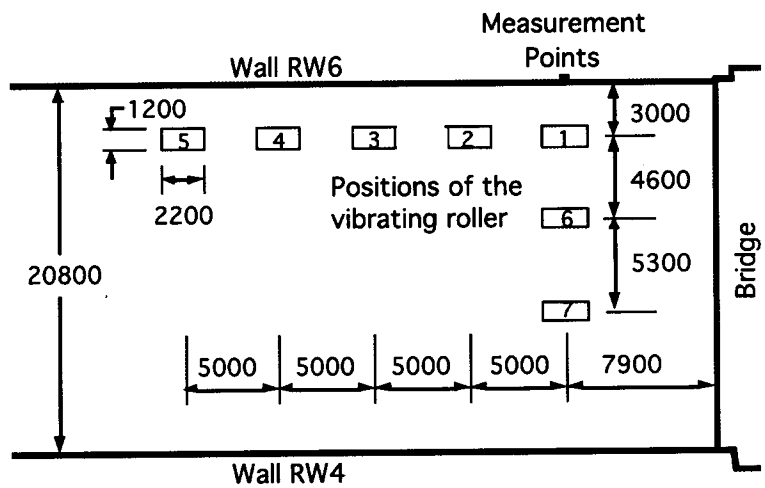


Fig. 6 Positions of the roller for attenuation measurements

### 4.2 Results

The natural frequencies of the wall were deduced from the records of free vibrations. An analysis using the Fast Fourier Transformation yielded dominant frequencies in the range of 15 to 45 Hz. In order to evaluate the dominant frequencies of the structure itself the free vibrations were isolated from the frequencies of the roller. The roller had a dominant frequency of 27.3 Hz and gave a maximum acceleration in vertical direction of about 6 m/s$^2$. The transfer functions for the horizontal and the vertical vibrations indicated dominant frequencies of about 16 Hz in both directions. This frequency is accepted to be the first natural frequency of the wall. Fig. 7 shows the transfer function for vertical vibrations. The transfer function eliminates the contribution of the vibrations from the drum of the Roller from the vibrations of the wall. The charts also show a distinct peak at a frequency of 32 Hz. This frequency may be accepted as a second natural frequency. It is thought that the first natural frequency (16 Hz) is a fairly reliable measure. Less confidence can be placed in the determination of the second natural frequency, due to the limitations of the experimental and computational procedure used.

Given the height of the wall at the time of the measurements (7.6 m), the density of the backfill (2 tonnes/$m^3$) and the natural frequency (16 Hz), the shear modulus G can be calculated. Based on the theory of free shear-type vibrations in a continuum, G was found to be 470 MPa, for an average shear strain level of $9.0 \times 10^{-4}$%.

From the records of free vibrations, a damping ratio of 4.0% was determined. This ratio is expressed as a percentage of critical damping.

In order to investigate the magnitude of the vibrations in relation to the proximity of the vibrating roller, the roller was moved to seven different positions (see Fig. 8). The maximum measured accelerations generated by the 5 tonne roller varied from 0.6 to 0.05 $m/s^2$. The attenuation curves have an exponential shape, as shown in Fig. 8. This figure shows the magnitude of vertical vibrations at the four measuring points for roller positions 1 to 5.

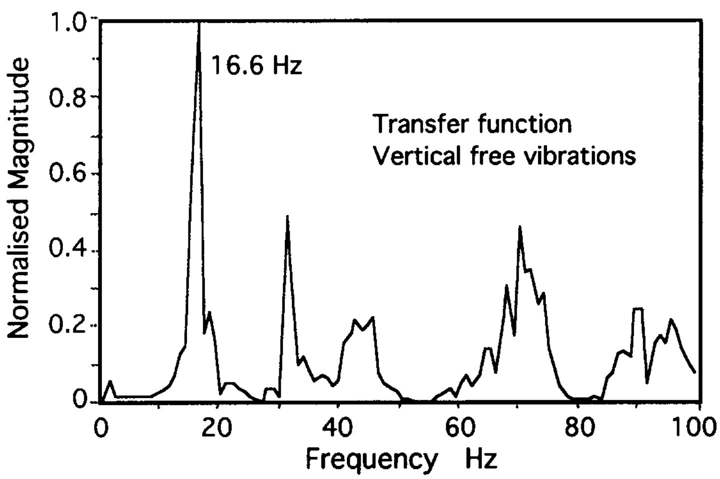


Fig. 7 Frequency distribution, vertical vibrations

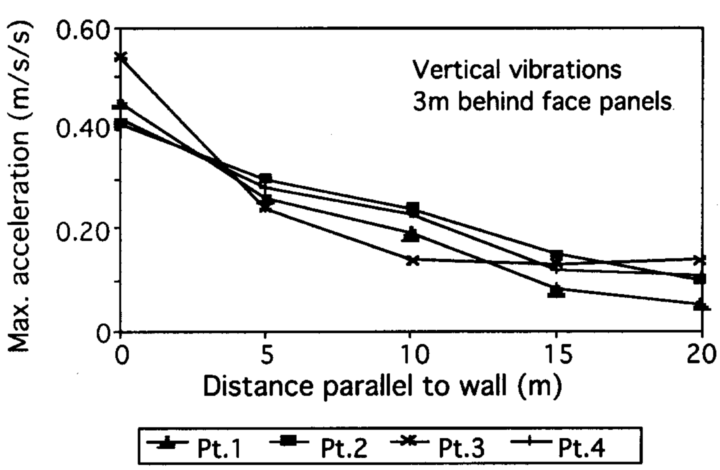


Fig. 8 Attenuation curves, vertical vibrations

## 4.3 Use of dynamic data

The dynamic data can be used for earthquake resistance design and for calculations of dynamic response of the wall due to any type of dynamic excitation. Also, the Shear Modulus gives information about the overall stiffness of the wall structure. The overall stiffness can be used for comparison purposes with the other walls of similar construction or for monitoring of changes of the same wall over a period of time.

It is the intention to repeat the measurements on the wall after a period of time, in order to investigate any changes in wall characteristics with time. It is hoped to extend the measurement to other reinforced soil walls in order to assess differences in behaviour between walls with clay backfill and synthetic reinforcement and walls with granular backfill and steel reinforcement.

# 5 CONCLUSIONS

Up to 100 mm lateral movement of the face of the wall was recorded. Average movement was in the order of 50 mm.

The internal movement of the wall, measured by rod extensometers, decreased gradually to zero at a distance of about 5 m from the face.

Strip tensions measured were less than 40 % of the design values.

The load eccentricity at the base of the wall was noticeable during construction but diminished after completion of the wall.

The measurement of dynamic response of the wall to induced vibration was successfully carried out using a 5 tonne roller. The high sensitivity of the accelerometers allowed the recording of vibrations that were generated by the roller even when the roller was located 20 m away.

The establishment of a data base of dynamic behaviour of walls may contribute to improved analytical procedures and could indicate whether a dynamic assessment of a reinforced soil wall can assist in the evaluation of the overall stability of such structures.

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# REFERENCES


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