USE OF MELTER SLAG AS AGGREGATE IN OPEN-GRADED EMULSION MIXES

Transfund New Zealand Research Report No. 112

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Transfund New Zealand Research Report No. 112

ISBN 0-478-11070-7
ISSN 1174-0574

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Opus International Consultants Ltd. 1998. Use of melter slag as aggregate in open-graded emulsion mixes. *Transfund New Zealand Research Report No. 112.* 29 pp. 6 Appendices.

Keywords: aggregate, bitumen, emulsion, melter slag, New Zealand, OGEM, overlay, pavement, roads, trials

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EXECUTIVE SUMMARY

Introduction

Iron slag, or Melter Slag, is a major by-product obtained during the steel manufacturing process, as at the New Zealand Steel Glenbrook plant, and ways to use the Melter Slag are always wanted. One way is to use crushed Melter Slag as aggregate in open-graded emulsion mixes (OGEMs) for Cold Emulsion Bituminous Mixes in road pavements.

Slag was used and tested in 1991 as an aggregate in the construction of access roads within the New Zealand Steel mill complex. Even though the slag aggregate was of lower crushing resistance than specified by Transit New Zealand (TNZ P/11P) it performed satisfactorily.

If aggregates with significantly lower crushing resistance than presently specified by Transit New Zealand are satisfactory for use in asphaltic mixes, the potential number of rock types available for producing aggregates for asphaltic mixes would be increased, leading to a more effective and economic utilisation of resources.

To evaluate further the performance of the melter slag, a trial was carried out on a section of state highway near the New Zealand Steel mill. The OGEM mixes were prepared and laid on the trial section in February 1994 by Bitumix Limited. Monitoring and subsequent testing was carried out by Works Consultancy Services Auckland Laboratory, now Opus International Consultants Limited, Auckland.

Site Details

The site chosen for the field trials was located on SH22 at its intersection with the Glenbrook Steel Mill Road; RP 0.00/7.37.

Three mix designs were used on specific parts of the intersection:

1. Conventional OGEM with Basalt aggregate,
2. Conventional OGEM with Melter Slag aggregate,
3. Fine mix with Melter Slag.

Monitoring the Overlay

Measurements were made the following times:

1. Before the OGEM overlay was constructed, i.e. before February 1994,
2. Immediately after construction of the overlay, in March 1994,
3. At 6 months after construction of the overlay, in September 1994,
4. At 12 months after construction, in March 1995,
4. At 24 months after construction, in March 1996, and
5. At 36 months after construction, in April 1997.

Measurements made on the trial sections before construction of the OGEM Overlay were:

(a) Pavement Deflection (by Benkelman Beam),
(b) Transverse Profile (by straight edge),
(c) Pavement defects map (by walkover survey),

and after construction, only, were:
(d) Skid resistance (by British Pendulum),
(e) Texture (by Sand circle),
(f) Density (by Nuclear Densometer),
(g) Transverse Profiles (by Electronic Profile Beam),
(h) Pavement defect maps (by walkover survey), in 1996 and 1997.

Conclusions

Behaviour of Trial OGEM Overlay

The overlay performed well to the end of the trial in 1997, with generally improved surface texture and skid resistance at most test positions during 1995-96. Except for fretting, no significant detrimental changes appeared to have occurred to skid resistance, surface texture, density and transverse profiles.

The effectiveness of the trial however was affected by the following problems:
1. The distressed turn area from SH22 to Glenbrook-Waiuku Road.
2. The transport of flushed bitumen onto the trial section during the very hot summer of 1995/96.
3. Traffic density information, although available, was not used at the time the trial was being set up. The trial section may have been inappropriate for evaluating an OGEM overlay.

Behaviour of Slag as Aggregate

Each batch of slag from the steel making process is likely to have different chemical and physical attributes. Therefore a batch to be used as aggregate should be tested for its crushing resistance, weathering, and PSV in order to design a satisfactory overlay mix.

Physical attributes of the final aggregate could be modified by using processes, like the Barmag process, to crush the slag in such a way that a more resistant aggregate could be created that would conform with the relevant TNZ Specifications.

ABSTRACT

Melter slag is a major by-product of the steel manufacturing process, and its potential for use as an aggregate in open-graded emulsion mixes (OGEMs), is the topic of this report. Crushed melter slag was first tested in 1991 for use in constructing access roads within a steel mill complex in New Zealand. Its performance was later trialled on a state highway intersection for about 4 years (1994-1997). The report details the results of the monitoring and evaluates its use as aggregate.

1. INTRODUCTION

Iron slag, also called Melter Slag, is a major by-product obtained during the steel manufacturing process, for example at the New Zealand Steel Glenbrook plant. At that plant it was used in 1989 as an aggregate in the construction of access roads within the steel mill complex.

The Slag Reduction Company Ltd which processes this by-product is always looking for ways to use the Melter Slag. One way was to use crushed Melter Slag as aggregate in open-graded emulsion mixes (OGEMs) for Cold Emulsion Bituminous Mixes used for road pavements.

Therefore the company in conjunction with Emoleum New Zealand (a subsidiary of Bitumix Ltd) trialled and tested the by-product in 1991, and a report, *Emoleum (NZ) & Slag Reduction Co. Ltd: Cold Bituminous Emulsion Trials*, was written by Works Consultancy Services Ltd (1992).

That report concluded that, even though the crushing resistance of the melter slag is generally in the range of 55 to 75 kN, which is significantly lower than the minimum of 130 kN specified in Transit New Zealand Specification P/11P:1984 for friction course aggregate, it is performing satisfactorily under loadings in excess of 100 tonnes, after about 10 years of trafficking.

To evaluate the performance of the melter slag, a trial was carried out on a section of state highway near the steel mill. The intersection of the Glenbrook-Waiuku Road and State Highway (SH) 22 was selected for the trial because it was close to the source of slag, and it has a high use by heavy traffic although the traffic data available were only approximate.

Testing of the primary materials was undertaken by Bitumix Limited, with a Weathering test carried out by W. Stevensons & Sons, and PSV (Polished Stone Value) testing on the crushed Melter Slag by Canterprise.

The OGEM mixes were prepared and laid on the trial section in February 1994 by Bitumix Limited. Monitoring and subsequent testing was carried out by Works Consultancy Services Auckland Laboratory, now Opus International Consultants Limited, Auckland, who prepared this report.

The implications which can be drawn from these previous field trials are that aggregates with significantly lower crushing resistance than presently specified by Transit New Zealand may be satisfactory for use in asphaltic mixes. If they are suitable, the potential number of rock types available for producing aggregates for asphaltic mixes would be increased, leading to a more effective and economic utilisation of resources.

2. OBJECTIVE

The objective of this study is to evaluate the performance of the melter slag, produced from the Glenbrook Steel Mill, as an aggregate in OGEMs for use on state highways in New Zealand.

3. SITE DETAILS

The site chosen for the field trials is located on SH22 at its intersection with the Glenbrook Steel Mill Road, RP 0.00/7.37 (Highway Information Sheet, Figure 3.1; site plan, Figure 3.2, and a view in Figure 6.6).

4. CONSTRUCTION DETAILS OF 1994 TRIAL OGEM OVERLAY

The OGEM overlaying operations were carried out for the trial over a two-day period, on 01 and 02 February 1994, by Bitumix Limited.

The sections of OGEM overlay consisted of three mix types. Two of the mix types were Melter Slag mixes, one of a Mix 2 aggregate and the second of a finer graded aggregate of Mix 2/3 specification, and the third was a control using basalt aggregate for comparison.

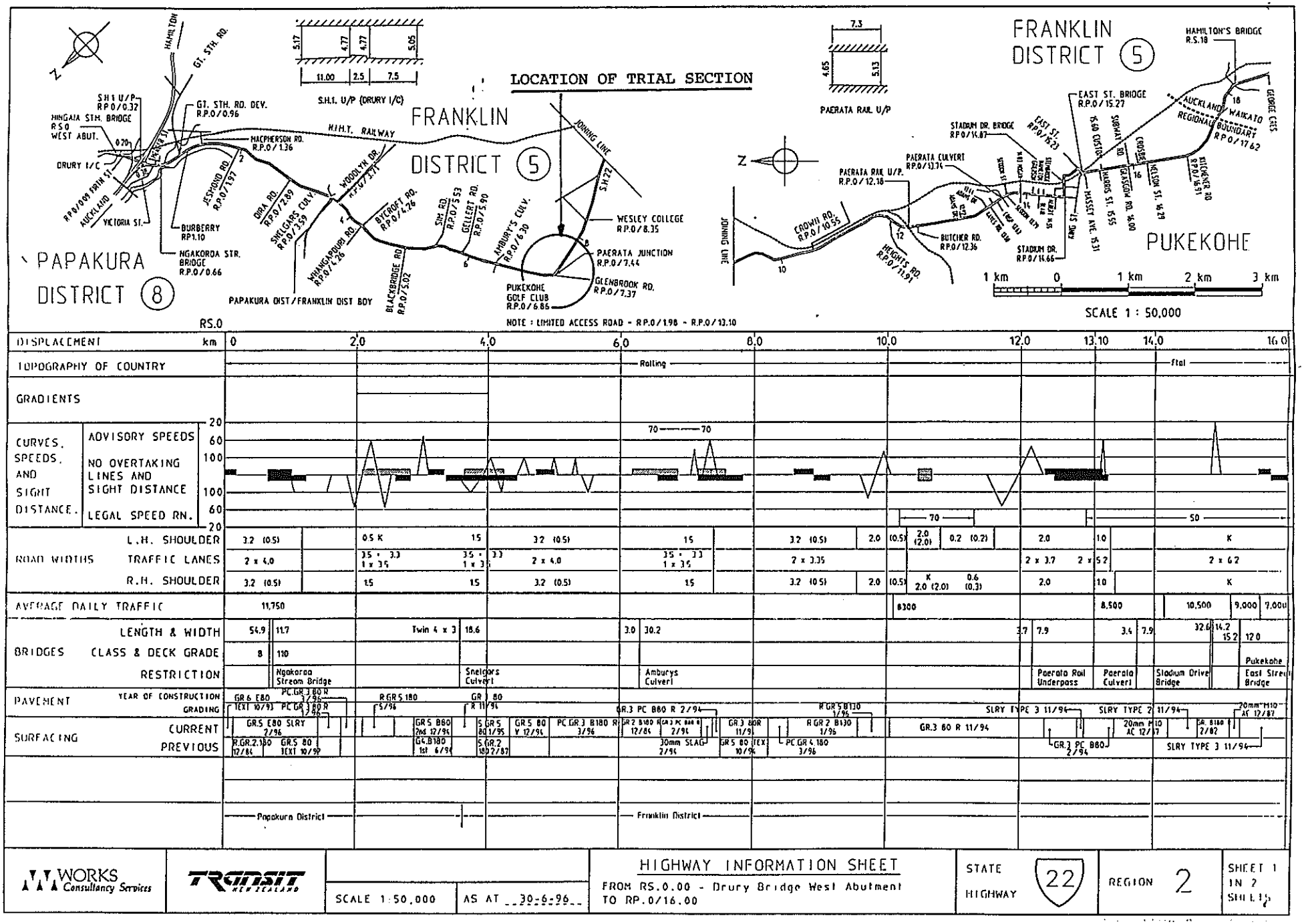
Before constructing the OGEM overlay, testing was undertaken on the CM60/200 bitumen emulsion and aggregates used in the different mixes. The results are detailed in Appendix 3.

The three mix designs were used on specific areas of the intersection as follows:

1.	Conventional OGEM with Basalt aggregate	Basalt Mix 2 used for Run 1a as Control
2.	Conventional OGEM as for (1), but with Melter Slag aggregate	Slag Mix 2 for Runs 1b, 4, 5 & 6
3.	Fine mix using Melter Slag	Slag Mix 2/3 for Runs 2 &3

The as-laid paver runs are indicated on Figure 6.1.
Laboratory tests were carried out on the samples of Mixes 2 and 2/3, and these test results are included in Appendix 3.

Figure 3.1 **Facsimile of Highway Information Sheet, from RS 0.00 - Drury Bridge west abutment to RP 0/16.00, showing location of trial section.**



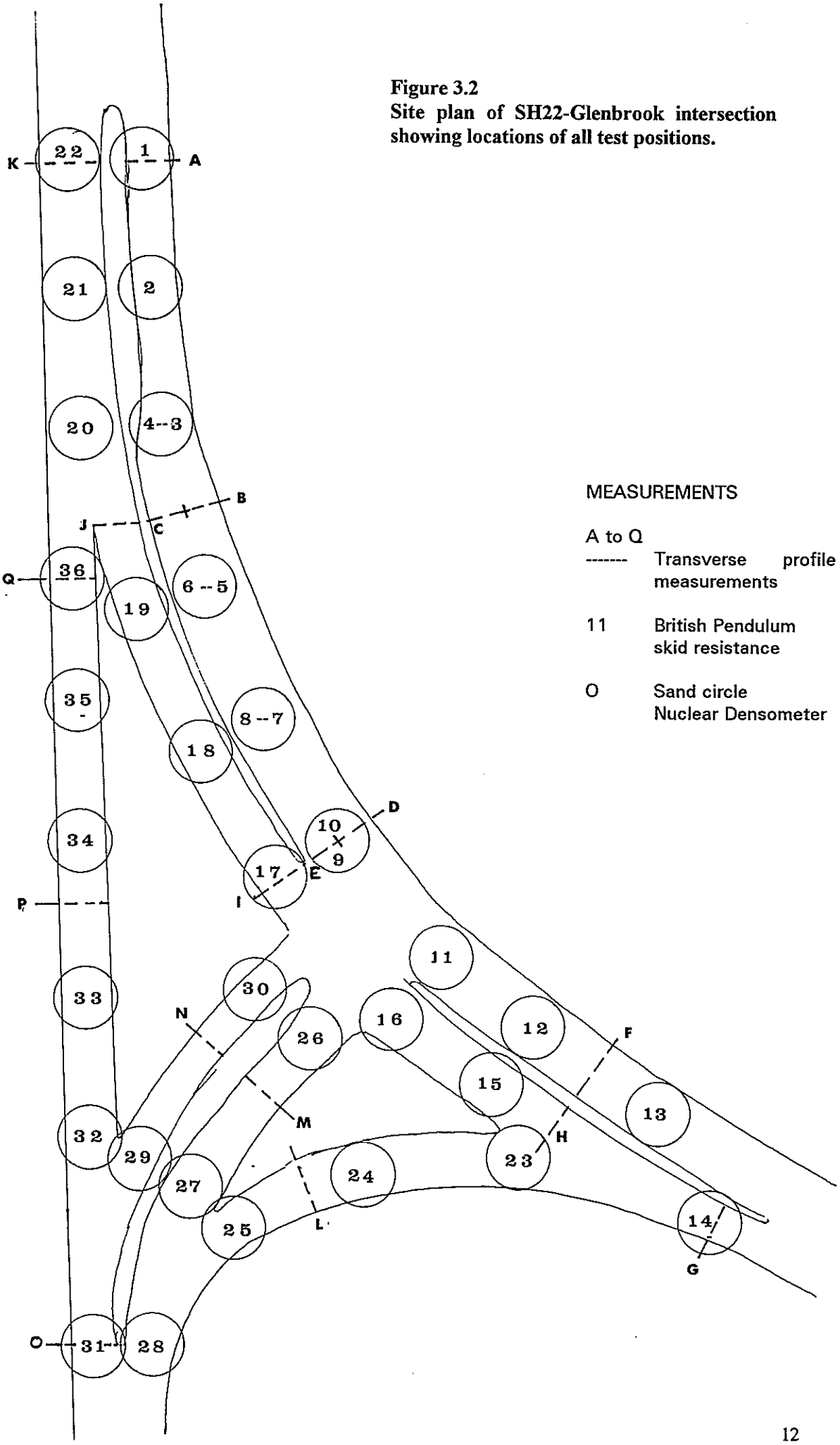


Figure 3.2
Site plan of SH22-Glenbrook intersection showing locations of all test positions.

5. MONITORING THE OVERLAY

5.1 Time of Monitoring

Measurements of specific parameters to monitor the OGEM Overlay were made at the following times:

1. Before the OGEM Overlay was constructed, i.e. before February 1994
2. Immediately after construction of the overlay, i.e. in March 1994
3. Monitoring at 6, 12, 24 and 36 months after construction of the overlay, i.e. in September 1994, and the months of March in 1995, 1996 and 1997.

5.2 Measurements Made for Monitoring

Measurements made on the trial section on SH22 before construction of the OGEM Overlay were:
(a) Pavement Deflection (by Benkelman Beam), recorded in Appendix 1,
(b) Transverse Profile (by straight edge), recorded in Appendix 2,
(c) Pavement Defects map (by walkover survey) recorded in Figure 3.1;

and after construction were:
(d) Skid resistance (by British Pendulum), recorded in Appendix 3,
(e) Texture (by Sand Circle), recorded in Appendix 4,
(f) Density (by Nuclear Densometer), recorded in Appendix 5,
(g) Transverse Profiles (by Electronic Profile Beam), recorded in Appendix 2,
(h) Pavement Defects maps (by walkover survey), recorded in 1996 (Figure 6.1) and 1997 (Figure 6.2).

5.3 Monitoring Before OGEM Overlay Construction

5.3.1 Pavement Deflections

The rebound deflection of a pavement under a standard wheel load and tyre pressure, as an indication of flexibility of a pavement, is determined by the Benkelman Beam. These measurements were carried out at 20 m intervals in both wheel tracks. Testing was carried out in accordance with TNZ Specification T/1:1977 (TNZ 1977) using an 8.24 tonne axle load.

Beam deflections were calculated in millimetres and the results of the tests are provided in Appendix 1.

5.3.2 Transverse Road Profiles

The transverse profiles across the road section were taken at 50 m test intervals, including measurements on all lanes and ramps.

As shown on Figure 3.2, 17 sites were measured. The test sites were located using the steel pins driven into the pavement, and were alphabetically coded A to Q.

Before 1994, a 3.0 m aluminium straight edge was used for these measurements and are tabulated in Appendix 2. All profile measurements taken after 1994 were taken using the electronic profile beam, details of which are discussed in Section 5.4.4.

5.3.3 Pavement Defects Map

All pavement defects were noted during the walkover survey before the overlay was constructed in February 1994, and were entered on a Defects Map. Defects were noted while measuring other parameters on the site.

5.4 Monitoring After OGEM Overlay Construction

Sets of measurements were taken immediately after the construction of the OGEM overlay, in March 1994, and at 6, 12, 24 and 36 months after construction which was during September 1994, and the months of March in 1995, 1996 and 1997 respectively.

5.4.1 Skid Resistance

Skid resistance measurements using the British Pendulum (Figure 5.1, following procedures given in TRRL Roadnote 27, Second Edition (TRRL 1969)), were taken in all wheel tracks, at 20-m marked longitudinal positions, shown on the site plan (Figure 3.2). The actual wheel tracks were determined and measured out laterally from the datum pins. Appendix 4 gives the actual measured offsets for these test positions.

5.4.2 Texture

Sand circle tests for pavement surface texture (Figure 5.2) were carried out to TNZ Specification T/3:1981 (TNZ 1981). They were taken in the same locations as the skid resistance measurements (Figures 3.2).

5.4.3 Density

Density measurements were taken at the same positions as those for skid resistance and texture (Figure 3.2), using a Troxler thin surfacing nuclear densometer gauge (Figure 5.2).

5.4.4 Transverse Road Profiles

Transverse profile measurements were taken at the alphabetically coded transverse locations (Figure 3.2), which before 1994 had been measured with the 3-m aluminium straight edge (Figure 5.3).

Profile measurements after overlay construction, however, were taken using the electronic profile beam equipment (Figure 5.4) described as follows.

Figure 5.1
TRRL British Pendulum
skid resistance testing machine.

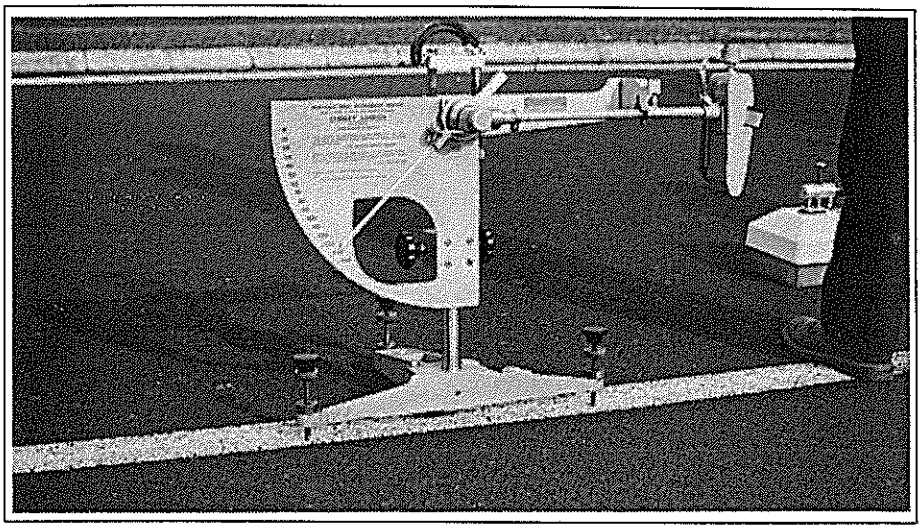


Figure 5.2
Troxler thin surfacing nuclear densometer for measuring density, and adjacent is the sand circle test for texture.

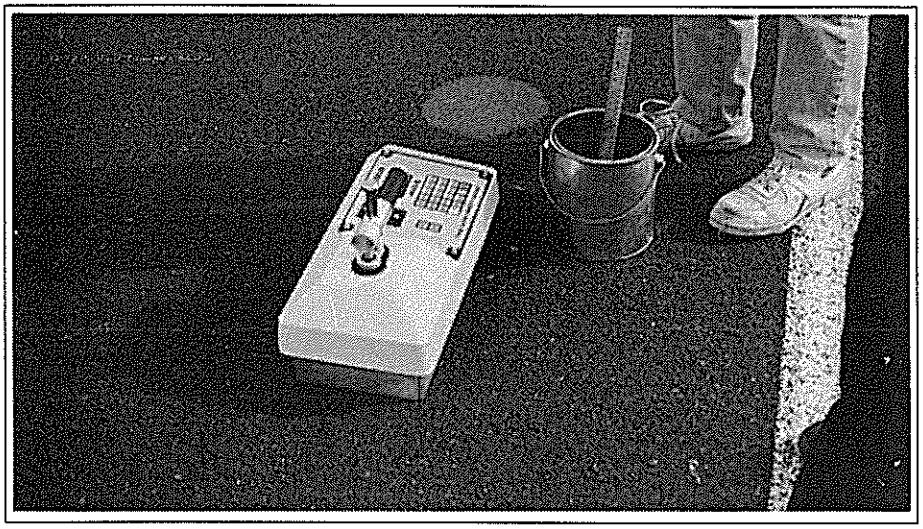
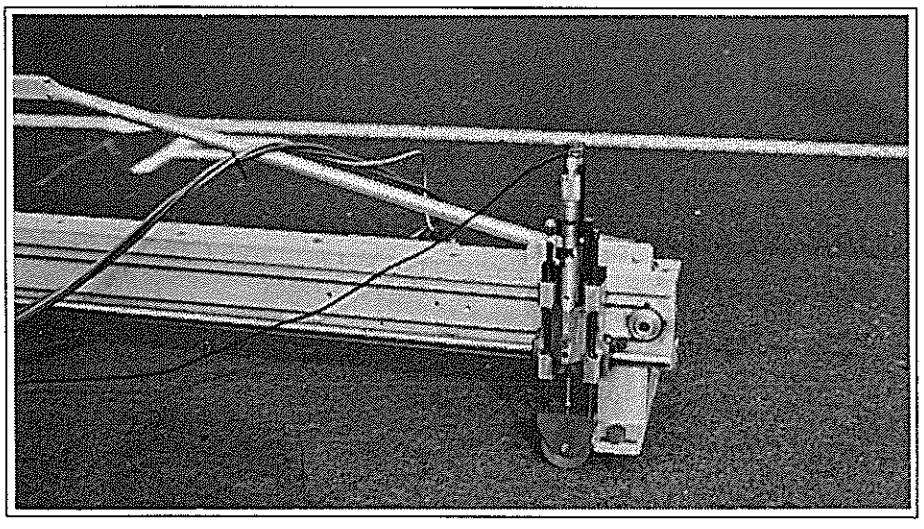


Figure 5.3
Transverse profiles were measured with straight edge before 1994.
The obvious lateral displacement of OGEM was first mapped in 1996 (Figures 6.1, 6.2).

Figure 5.4
Transverse Profile Beam vertical measuring system was used to measure transverse road profiles after 1996.



Electronic Profile Beam
This equipment consists of an aluminium beam along which a linear displacement transducer assembly is electrically driven transversely. The transducer is attached to a small wheel in contact with the pavement surface. The transducer accurately measures the displacement between the beam and road surface as it travels along the length of the beam.

The position of the transducer along the beam and the displacement of the transducer in the vertical plane are electronically conditioned with the outputs connected to an XY graphic plotter. The X axis is scaled to cover 3.6 m transverse travel along the beam equivalent to 360 mm chart displacement. The Y axis is scaled to give the vertical displacement amplified by a factor of x = 5 (based on calibration procedures). Thus 1 mm displacement = 5 mm chart recorded displacement of pavement profile.

The graphic plots in Appendix 2 accurately indicate the surface profile with enough resolution to show the texture of the pavement surface.

5.4.5 Pavement Defects Maps
All pavement defects were noted during the walkover surveys made while monitoring the OGEM overlay in 1996 and 1997, on Pavement Defects maps. The maps for the two years are shown as Figures 6.1 and 6.2 respectively.

6. RESULTS OF MONITORING

The results of the measurements taken during monitoring the trial are presented in two sets:

- Measurements made before OGEM overlay was constructed (before February 1994), called the control;
- Measurements made after OGEM overlay was constructed (since March 1994):
  - immediately after construction (March 1994),
  - 6 months after construction (September 1994),
  - 12 months after construction (March 1995),
  - 24 months after construction (March 1996),
  - 36 months after construction (April 1997).

6.1 Measurements Made Before OGEM Overlay Construction

6.1.1 Pavement Deflections
Benkelman Beam deflections on the trial section were generally < 0.6 mm except for some test positions. The maximum recorded deflection was 1.14 mm on the decreasing side (inside of a curve) of SH22 at 80 m in the outer wheel track. The individual test results for each site location are supplied in Appendix 1.

6.1.2 Transverse Road Profiles

The 3-m straight-edge profile results are tabulated in Appendix 2.

6.1.3 Pavement Defects Map

Generally, before the overlay, the whole intersection showed signs of "flushing" (which is excess binder creating a smoothed surface).

An area of the intersection with Glenbrook Road indicated signs of "shoving" (i.e. lateral displacement of pavement structure caused by braking, turning, or accelerating vehicles) with associated tension cracking. This distress was caused by tyre loadings from heavy vehicles turning sharply from SH22 into Glenbrook Road and inadequate pavement thickness or compaction. This area was repaired by Works Civil Construction Limited before the trial section was overlaid with the OGEM.

6.1.4 Materials Testing

Before constructing the OGEM overlay, mix designs and testing were undertaken on the CM60/200 bitumen emulsion and on the aggregates used in the different mixes. The results are detailed in Appendix 3.

Bitumix Limited carried out the following tests:

- Mix Designs for the three mixes (see Section 4 of this report for details).
- Crushing Resistance test (to determine resistance to breakdown or crushing of aggregate particles under load of 130 kN) on the grade 2 slag aggregate to NZS3111:1986 Test 14 (SANZ 1986).

This test gave an incorrect value of 125 kN. The test report shows that 21.68% fines were generated at a load of 230 kN, which is well outside the range limits of 9% - 11% allowable in accordance with the standard above.

Stevensons carried out the following tests:

- Weathering test (to detect changes in rock caused by exposure to air and water) on the slag aggregate to NZS3111:1986: Test 15 (SANZ 1986).

The University of Canterbury carried out the following test:

- Polished Stone Value (PSV, a measure of how stone will polish under standard traffic conditions) of the 10 mm slag aggregate.

6.2 Measurements Made After OGEM Overlay Construction

Figure 3.2 shows the test locations. Data for each successive annual monitoring task have been tabulated in Tables 6.1, 6.2 and 6.3, in which the data are divided into groups relating to mix type, as follows: mean of all sites; average for mix using basalt (the control mix); average for the two mixes using melter slag (the test mixes).

The sets of monitoring are: pre-overlay data (before March 1994), first post-overlay (March 1994), second (September 1994), third (March 1995), fourth (March 1996) and fifth (April 1997) monitoring cycles.

6.2.1 Skid Resistance

The minimum specified skid resistance value for a New Zealand state highway, according to Transit New Zealand requirements which are based on TRRL Roadnote No. 27 (1969), is 55 BPN (British Pendulum Number). Figure 5.1 shows the BP skid resistance testing machine in action.

Test results taken on the OGEM to date indicate skid resistance values ranging from a low of 58 to a high of 84 with most results lying between 60 to 70. Table 6.1 includes successive measurements from March 1994 to April 1997, for comparison.

During the first 12 months after construction (1994-95), the values tended to increase slightly. This increase would be expected because of weathering and wear on the pavement surface where excess bitumen may have been present immediately after laying the OGEM.

During the second 12-month period (March 1995-96), the general trend was a reduction in skid resistance. With the hot summer, flushing from the chipseal on Glenbrook Road had occurred and some bitumen has been carried on tyres onto the OGEM trial section. Skid resistance values for this section reduced from high BPN of 60 to low of 40 on the Glenbrook–Drury link.

Over the third 12-month period (March 1996 - April 1997), the skid resistance values again tended to decrease, and resulted in the average BPN reducing from 66 at start of the trial to 62.

This decreasing trend is inevitable as the aggregate in the mix tends to polish and contaminants from vehicles (oil, grease, etc.) are spread on the surface. During summer months this contamination does not get washed off.

Table 6.1 Trends in skid resistance (BPN) for all sites over the period of the trial (1994-97).

Skid Resistance (BPN)				
Year	1994	1995 *	1996	1997
Average (all sites)	66.3	70.3	59.9	59.7
Average (Basalt)	66.5	68.8	48.0	48.5
Average (Slag)	66.1	70.5	62.2	61.8

* 1995 data does not include measurements at all test positions

6.2.2 Texture

Test results (Table 6.2) show the average sand circle diameter at each test position. These range from a minimum of 195 mm to a maximum of 365 mm, but generally the diameters range between 240 mm and 280 mm. Table 6.2 includes all measurements to April 1997, and Figure 5.2 shows a sand circle.

The surface texture during the first 12-month period (1994-95) had changed significantly at test positions 11, 27, and 29. Diameters increased by approximately 60 mm at these positions on all Mix 2/3 (Slag) areas. However the significance of these changes has yet to be determined.

During the next 12-month period (1995-96), a dramatic increase in diameters occurred where the skid resistance values decreased, i.e. where transport of bitumen from Glenbrook Road had occurred in the summer of 1996 (see Section 6.2.1 of this report). Generally the trend indicated a slight increase in sand circle diameters.

Over the last 12-month period (1996-97), although the surface textures remained much the same, the overall trend from 1994 was a decrease in macro-texture.

Table 6.2 Trends in sand circle diameters (mm), indicating changes in surface texture, for all sites over the period of the trial (1994-97).

Sand Circle Diameter (mm)				
Year	1994	1995 *	1996	1997
Average (all sites)	258	264	265	266
Average (Basalt)	291	292	311**	311**
Average (Slag)	251	253	256	257

* 1995 data does not include measurements at all test positions.

** Large increase in diameter caused by transport of flushed bitumen from the chipseal of Glenbrook–Waiuku Road onto OGEM trial section.

6.2.3 Density and Voids

Thin surfacing Nuclear Densometer (NDM) test results are listed in Table 6.3 and includes all measurements taken from March 1994 to April 1997. Figure 5.2 shows the Troxler densometer in use.

Although the density values are variable, they tend to show a slight densification of the pavement, with densities increasing after the OGEM overlay, by approx. +60 to 90 kg/m^3 for all sites. Densities range from a low of 2000 kg/m^3 to a high of 2500 kg/m^3, with a range between approximately 2300 to 2400 kg/m^3. The basalt mixes tend to have higher densities, as expected, that are generally in the range from 2400 to 2500 kg/m^3.

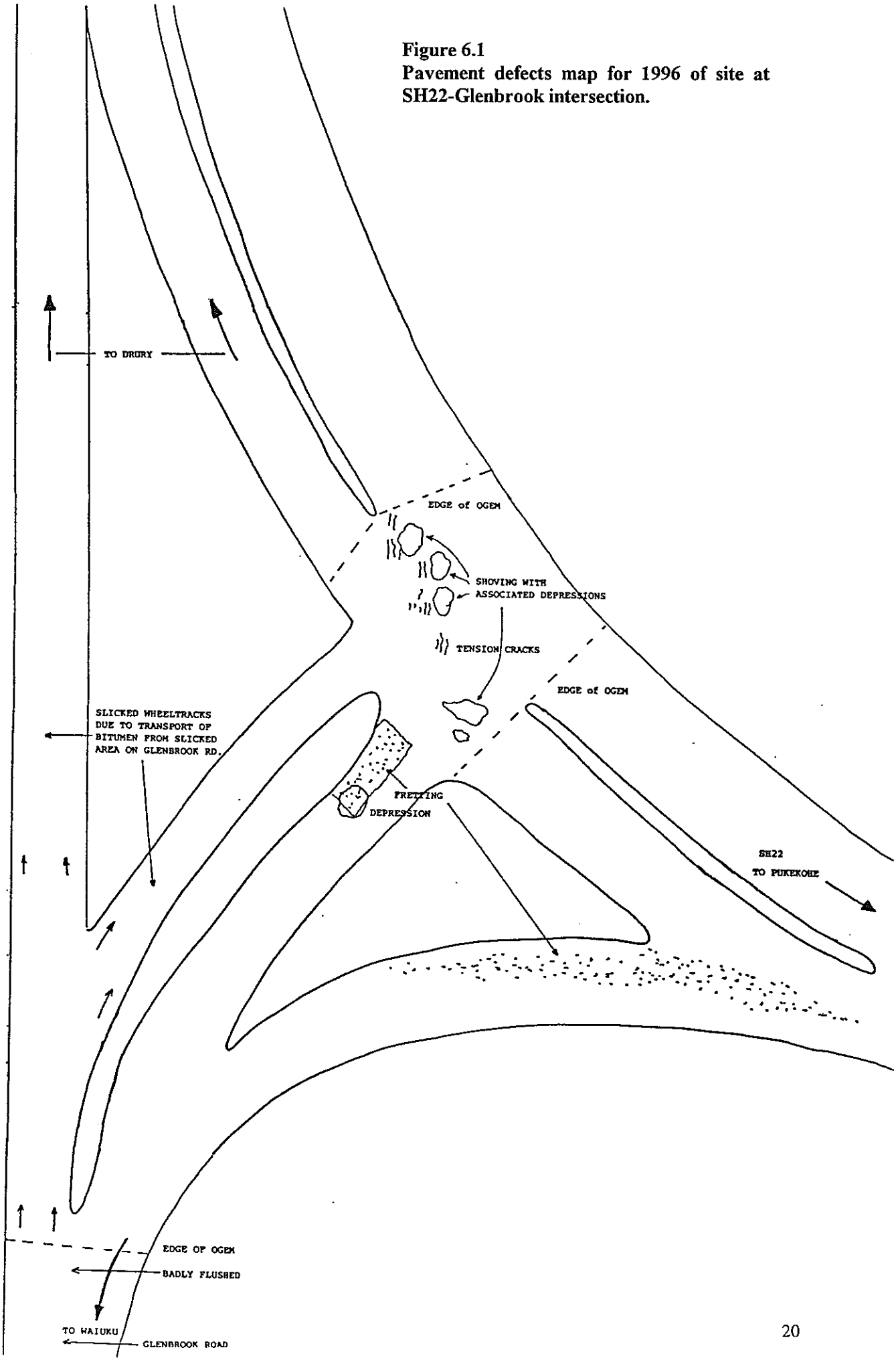
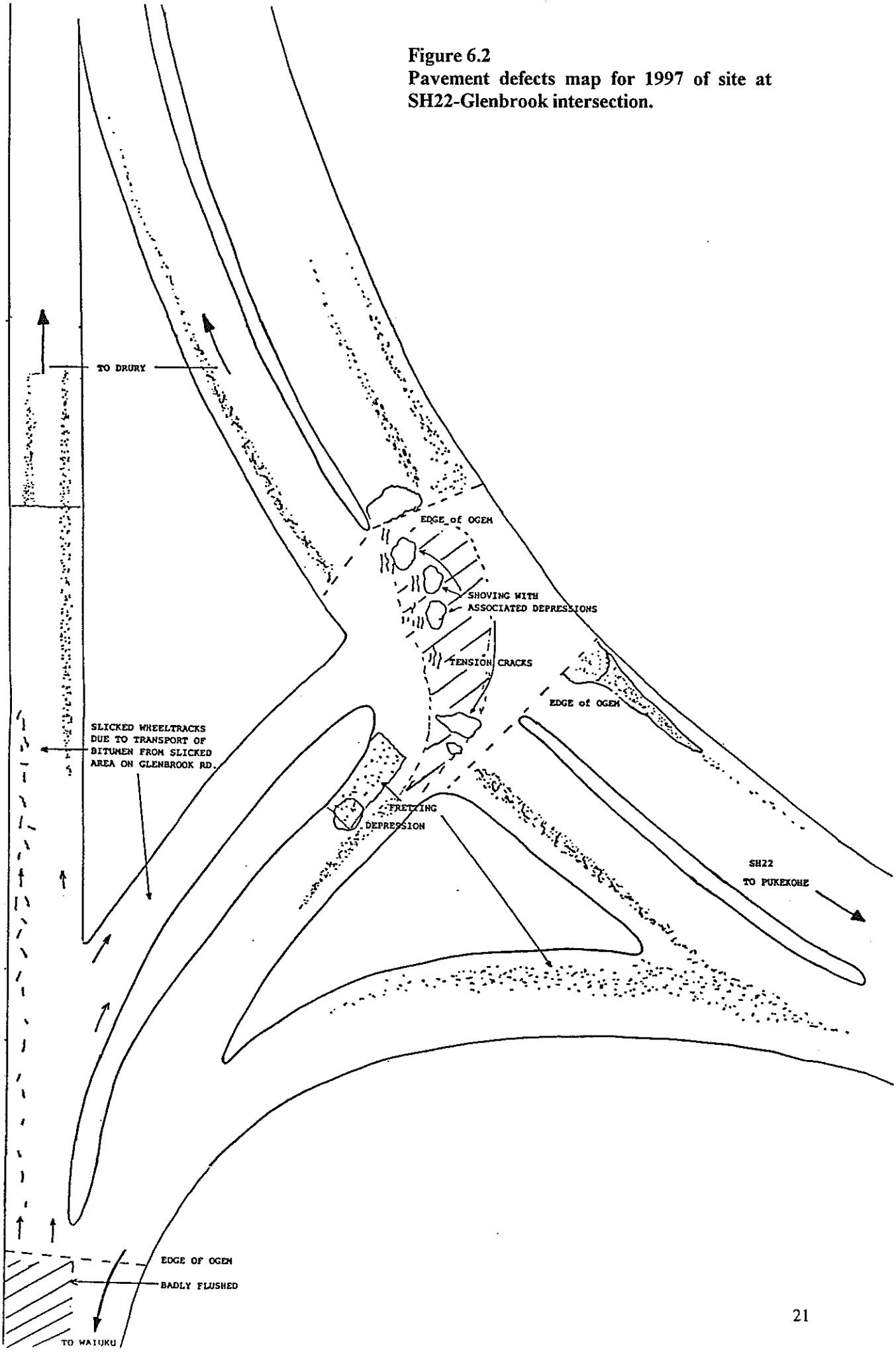


Figure 6.1
Pavement defects map for 1996 of site at SH22-Glenbrook intersection.

Figure 6.2
Pavement defects map for 1997 of site at SH22-Glenbrook intersection.



Further measurements made in March 1996 showed a slight increase in densities on the basalt mix section, but a decrease in densities of the slag mixes.

For the last 12-month period (1996-97), the densities appeared on average to increase from the baseline (i.e. the first monitoring of the OGEM overlay) by 50 kg/m^3 average for all sites and 25 kg/m^3 for the OGEM basalt mix. These increases would be conservative because the increased fretting of the pavement surface influenced the densometer readings.

Table 6.3 Trends in densities measured by Nuclear Densometer (NDM) (in kg/m^3), indicating densification from trafficking, for all sites over the period of the trial (1994-97).

NDM Density (kg/m^3)				
Year	1994	1995 *	1996	1997
Average (all sites)	2307	2403	2300	2360
Average (Basalt)	2478	2541	2497	2525
Average (Slag)	2271	2265	2256	2323

* 1995 data does not include measurements at all test positions

6.2.4 Transverse Road Profiles

All transverse profiles were taken at the same locations for all sets of measurements. The profiles measured before construction of the overlay were made with the 3-m straight edge (Figure 5.3), but the OGEM overlay profiles were measured with the electronic profile beam as this equipment gives a much more detailed record of the surface profile. The profile plots for the 17 test positions are given in Appendix 2. Figure 5.4 shows the Transverse Profile Beam in use.

The second, third and fourth sets of profile recordings taken for each test position have been superimposed on the plot of the profile recorded immediately after overlay construction (the base datum). This was done to determine the extent, if any, to which rutting in the wheel tracks or other pavement surfacing defects, e.g. flushing, fretting (i.e. ravelling or the loosening of aggregate from a pavement surface) had developed.

Considering the accuracy of the measurement system (readable to 0.1-0.2 mm accuracy) in the vertical plane, the plots show no significant indication that displacement in the wheel tracks has occurred at any of the test positions.

6.2.5 Pavement Defects Maps

A defect map was compiled during the 1996 assessment (Figure 6.1) and a second shows the surfacing defects that were noted in April 1997 (Figure 6.2).

- **1996 Pavement Defects Map**

The visual assessment has indicated that the most notable defect has occurred in the right turn area into Glenbrook Road from SH22 (Figure 6.1). This area had been repaired before construction of the OGEM overlay in February 1994. Here high lateral tyre loading from turning heavy vehicles had caused shoving, making the pavement "pucker" up into ridges, similar to corrugations, that were up to 80 mm in depth. Figure 5.4 shows the extent of the shoving with deformations that are more than 50 mm in depth, as measured by the straight edge.

The shoving has continued at this location and the pavement has now developed areas of cracking caused by the tensile stresses forming in the pavement (Figure 6.4). Water now has egress into the basecourse and sub-base layers.

Also noted during the 1995 monitoring was the fretting of the surface, especially along the left turn lane decreasing SH22 into Glenbrook Road. This fretting did not appear to have developed any further by March 1996.

The 1995-96 summer period was generally very hot with above average temperatures (which were 26-32°C). Figure 6.6 shows flushed bitumen from Glenbrook Road chipseal that has been transported by vehicle tyres onto the OGEM of the Glenbrook-Drury link. This flushing resulted in a marked increase in sand circle diameter (i.e. decreased texture) and decrease in skid resistance.

- **1997 Pavement Defects Map**

The map (Figure 6.2) shows the pavement defects noted during the 1997 assessment of the OGEM project. Many of the defects noted in 1996 had continued to develop, and they are as follows:

- Fretting: was the most notable development (Figure 6.3).
- Tension Cracking: had developed in the pavement in the right turn lane of the Glenbrook Road but had not increased since 1996. Some of the tension cracks have since closed up because of the kneading effect from the turning vehicles (Figure 6.4).
- Shoving: does not appear to have changed significantly since the 1996 assessment (Figure 6.5).
- Alligator Cracking: had developed over the 1996-97 period as it had not been visible in the 1996 survey.
- Flushing: was not a fault with the OGEM itself but was an introduced effect of flushing from the Glenbrook-Waiuku Road chipseal that had been transported by vehicle tyres to the OGEM overlay (Figure 6.6).

6.3 Grading Change

The crushing resistance values of the melter slag measured in the preliminary trial on the Steel Mill roads, in 1991, had been in the range of 55 to 75 kN. These are low values. However the testing carried out for this trial indicated the melter slag mix had a crushing resistance of 125 kN, which is approximately the requirements of TNZ Specification P/11P:1984 for Friction Course aggregate.

If the material is left to weather, it increases in hardness with time. Also methods of producing the melter slag can influence the results of a crushing resistance test significantly. For example, materials crushed with a "Barmag" type crusher can give a higher crushing resistance value because the angular corners and edges of the aggregate particles are rounded off.

During the field monitoring of the trial section, 300 mm square sections of the OGEM with slag aggregate were cut out of the wheel tracks in the pavement. These samples were taken to the laboratory to remove the binder by solvent extraction in order to carry out particle size gradings on the residual aggregate.

This grading was then compared to the gradings carried out on samples taken and tested during laying the OGEM in 1994. Table 6.4 gives the results of this testing, and records of the tests and specifications for the OGEM overlay are in Appendix 3.

Table 6.4 indicates a change in the percentage passing both the 1.18 mm and 300 μm sieves. The change in particle size distribution is caused by detritus (seen within the sample) from traffic being pushed through the pavement surface. Note that the 9.50 and 4.75 mm particle size distributions have not changed significantly (-1%).

Again, the gradings listed in Table 6.5 indicate that the grading of the Mix 2/3 OGEM overlay does not appear to have changed over the three year period. There were no visible signs of detritus in this mix.

Figure 6.3
Mix 2 Slag OGEM pavement on SH22 lanes shows fretting, as compared with the fine Mix 2/3 Slag at the intersection.

Figure 6.4
Tension cracks, associated with the lateral displacements shown in Figure 5.4, developed in the pavement.

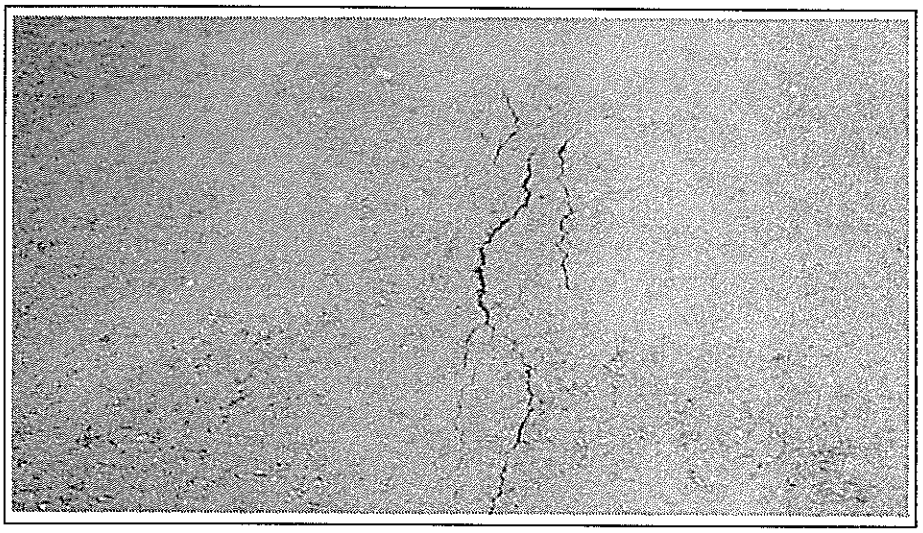


Figure 6.5
Shoving at the intersection was evident during the entire trial, and shown on 1996 and 1997 maps (Figures 6.1, 6.2).

Figure 6.6
Trial site at intersection of SH22 and Glenbrook-Waiuku road, showing transport of flushed bitumen onto the OGEM.

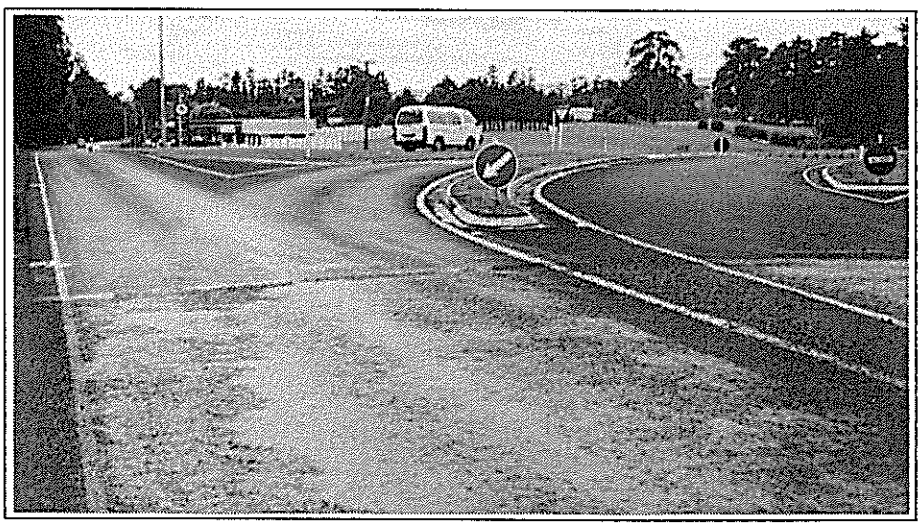


Table 6.4 Grading change of melter slag aggregate in Mix 2 slag OGEM overlay (sampled from Site 36, Left Wheel Track, in 1997).

MIX 2 Slag			
Particle Size	**Mix Design**	**1994 As Laid**	**1997 As Sampled**
13.2mm	100	100	100
9.50mm	97.8	100	99
4.75mm	48.4	59	58
2.36mm	24.2		
1.18mm	14.6	16	21 *
600μm	9.4		
300μm	6.2	7	11 *
150μm	3.9		
75μm	2.2	3	3

* Detritus present

Table 6.5 Grading change of melter slag aggregate in Mix 2/3 slag OGEM overlay (sampled from Site 29, Left Wheel Track, in 1997).

MIX 2/3 Slag			
Particle Size	**Mix Design**	**1994 As Laid**	**1997 As Sampled**
13.2mm	100	100	100
9.50mm	100	100	100
4.75mm	75.7	83	84
2.36mm	46.1		
1.18mm	28.8	34	35
600μm	18.9		
300μm	12.2	16	17
150μm	7.7		
75μm	4.3	7	8

7. CONCLUSIONS

7.1 Behaviour of Trial OGEM Overlays

Monitoring the trial for 36 months, from 1994 to 1997, showed that the OGEM overlay was performing well under the increasing traffic loadings. The intersection carried a considerable traffic loading of heavy vehicles, which develop high lateral tyre loadings when turning into and from the Glenbrook-Waiuku Road.

Surface texture and skid resistance generally improved at most test positions during the first 12-month period, and although no significant detrimental changes appeared to have occurred to skid resistance, surface texture, density, and transverse profiles, fretting is the main fault.

Some repair work was undertaken on the turning lane to Glenbrook Road early in 1994, and this area was then re-surfaced with the OGEM overlay. The pavement defect mapping indicates that a localised displacement of the pavement surface is continuing in this area possibly because compaction during the repair of the underlying basecourse layers was inadequate.

The increase in fretting is the pavement fault that has developed with time, with subsequent development of minor alligator cracking in the wheeltracks. This fault was very noticeable on SH22 at the intersection with Glenbrook-Waiuku Road, along the outer wheeltracks on the curved parts of the intersection. The fretting is the result of dynamic forces on the individual slag-aggregate particles and of loss of adhesion of the emulsion binder to these particles in the longer term.

The very hot summer of 1995-96 resulted in transport of bitumen from the flushed section of Glenbrook Road to the OGEM trial section, with a marked decrease in skid resistance on the Glenbrook-Drury link as a result. Notwithstanding this contamination problem of flushing, the general trend shows that skid resistance has been constant since the 1996 monitoring, after a decrease of approximately 5 BPN since the OGEM trial was laid in 1994. The 1997 skid resistance is still satisfactory in terms of the minimum value required for state highways (55 BPN).

Conclusion

The effectiveness of the trial was affected by the following problems:

1. The distressed turn area from SH22 to Glenbrook-Waiuku Road.
2. The transport of flushed bitumen onto the trial section during the very hot summer of 1995/96.
3. Traffic density information, although available, was not used at the time the trial was being set up. The trial section may have been inappropriate for evaluating an OGEM overlay.

7.2 Behaviour of Slag as Aggregate

The minimum crushing resistance specified by TNZ for friction course is 130 kN. Although the crushing resistance of the slag aggregate used in the earlier trial on the Steel Mill roads was determined to be much lower than that of basalt which was the rock type considered in the specification, those trial results showed that this low crushing resistance had no apparent detrimental effects on the performance of slag as an aggregate when bitumen-coated. One reason for this is that the binder possibly has a lubricating effect which allows movement without abrasion and stops the stones from crushing. As the initial materials testing was minimal, some of the data obtained may have been incomplete and not shown this effect.

The steel-making processes that produce the Melter Slag by-product may have changed and may possibly have produced a harder material. For example, each batch of slag may be different according to the composition of the basic materials in the steel-making process.

Also the crushing resistance test is influenced by both aggregate shape and hardness. Thus these physical attributes of the final aggregate could be modified by using processes, like the Barmag process, to crush the slag in such a way that a more resistant aggregate could be created that would conform with the relevant TNZ Specifications.

Conclusion
As each batch of slag is likely to have different chemical and physical attributes, a batch to be used as aggregate should be tested for its crushing resistance, weathering, and PSV in order to design a satisfactory overlay mix.

The OGEM trial section did perform satisfactorily, given the very high traffic loadings on this road section, during the 4 years of the monitoring trial. However since the trial ended in 1997, the surface has fretted away at a rapidly increasing rate. This latest deterioration may be related to some other reason, such as weathering of the emulsion causing chemical decomposition and loss of adhesion and flexibility.

8. REFERENCES

SANZ 1986. Methods of test for water and aggregate for concrete. *NZS 3111:1986 Tests 14, 15.* Standards Association of NZ, Wellington.

Transit New Zealand (TNZ). 1977. Standard test procedure for Benkelman Beam deflection measurements. *TNZ Specification T/1:1977.*

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TRRL. 1969. A guide to the structural design of flexible and rigid pavements for new roads. *TRRL Roadnote No. 27,* Second Edition. ISBN 11 550060X. Transport & Road Research Laboratory (TRRL), Crowthorne, England.

Works Consultancy Ltd. 1992. Trial on roads in Glenbrook steel mill complex. Works Consultancy Ltd, Auckland, unpublished report.

APPENDIX 1
BENKELMAN BEAM RESULTS

WORKS Consultancy Services

AUCKLAND ENGINEERING LABORATORY
Cnr Fanshawe St & Daldy St, Auckland
P.O.Box 5848, Wellesley St, Auckland 1
Phone 0-9-309 6863, Fax 0-9-303 4479

BENKELMAN BEAM - TEST SHEET

Tested in accordance with NRB T/1 1977 (Modified)

JOB NAME: OGEM TRIALS - STATE HIGHWAY 22 Ref PR3-0112

LOCATION: PUKEKOHE to WAIUKU (Left turn decreasing)

TESTED BY: I MORAR DATE: 01/03/94 JOB No: 39099.00

PAVEMENT DESCRIPTION

SEAL: Chipseal ASPHALTIC CONC. TEMP.: - °C DEPTH TEMP. RECORDED: mm TIME: A.M.

BASECOURSE: SUB BASE:

S.I.M.: SUBGRADE:

AXLE LOAD: 8.33 Tonnes TYRE PRESSURE: 520 kPa TYRE PRESSURE GAUGE No: FTS11-1

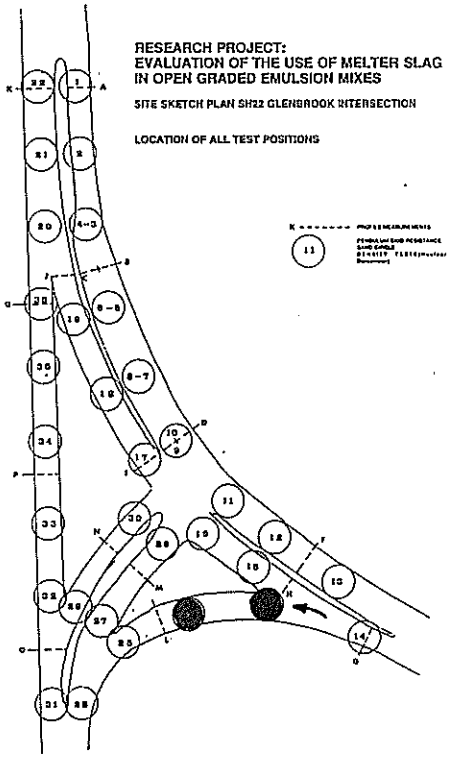
BEAM No: 4 DIAL GAUGE No: S30

Folio No: FS/94/41 Test No: 1825

Sheet 1 of 6

Distance (Metres)	FAST LANE [REBOUND DEFLECTIONS (mm)]		Distance (Metres)	SLOW LANE [REBOUND DEFLECTIONS (mm)]	
	Outer wheel	Inner wheel		Inner Wheel	Outer wheel
0	0.66	0.76			
20	0.56	0.36			

REMARKS



STATISTICAL ANALYSIS OF TEST DATA

NUMBER OF TESTS:	4
AVERAGE REBOUND DEFLECTION:	0.59mm
STANDARD DEVIATION:	0.15
COEFFICIENT OF VARIATION:	25.3%
95 PERCENTILE:	0.81mm

CHECKED BY: S Kaukas DATE: 14/03/94

APPROVED SIGNATORY: C Harrison

TELARC

THIS LABORATORY IS REGISTERED BY THE TESTING LABORATORY REGISTRATION COUNCIL OF NEW ZEALAND. THE TESTS REPORTED HEREIN HAVE BEEN PERFORMED IN ACCORDANCE WITH ITS TERMS OF REGISTRATION. THIS REPORT MAY NOT BE REPRODUCED EXCEPT IN FULL.

WORKS Consultancy Services

AUCKLAND ENGINEERING LABORATORY
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P.O.Box 5848, Wellesley St, Auckland 1
Phone 0-9-309 5863, Fax 0-9-303 4470

BENKELMAN BEAM - TEST SHEET

Tested in accordance with NRB T/1 1977 (Modified)

JOB NAME: OGEM TRIALS - STATE HIGHWAY 22 Ref PR3-0112

LOCATION: WAIUKU to PUKEKOHE (Right turn)

TESTED BY: I MORAR - R KWAN DATE: 01/03/94 JOB No: 39099.00

PAVEMENT DESCRIPTION

SEAL: Chipseal ASPHALTIC CONC. TEMP.: - °C DEPTH TEMP. RECORDED: mm TIME: A.M.

BASECOURSE: SUB BASE:

S.I.M.: SUBGRADE:

AXLE LOAD: 8.33 Tonnes TYRE PRESSURE: 520 kPa TYRE PRESSURE GAUGE No: FTS11-1

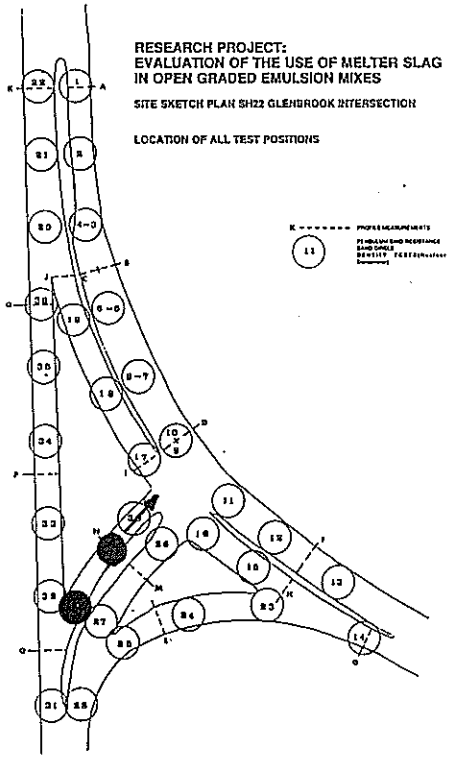
BEAM No: 4 DIAL GAUGE No: S30

Folio No: FS/94/41 Test No: 1825

Sheet 2 of 6

Distance (Metres)	FAST LANE [REBOUND DEFLECTIONS (mm)]		Distance (Metres)	SLOW LANE [REBOUND DEFLECTIONS (mm)]	
	Outer wheel	Inner wheel		Inner Wheel	Outer wheel
0	0.46	0.34			
20	0.66	0.38			

REMARKS



STATISTICAL ANALYSIS OF TEST DATA

NUMBER OF TESTS:	4
AVERAGE REBOUND DEFLECTION:	0.46mm
STANDARD DEVIATION:	0.12
COEFFICIENT OF VARIATION:	26.8%
95 PERCENTILE:	0.65mm

CHECKED BY: S Kaukas DATE: 14/03/94

APPROVED SIGNATORY: C Harrison

WORKS Consultancy Services

AUCKLAND ENGINEERING LABORATORY
Cnr Fanshawe St & Daldy St, Auckland
P O Box 5848, Wellesley St, Auckland 1
Phone 0-9-309 6863, Fax 0-9-303 4470

BENKELMAN BEAM - TEST SHEET

Tested in accordance with NRB T/1 1977 (Modified)

JOB NAME: OGEM TRIALS - STATE HIGHWAY 22 Ref PR3-0112

LOCATION: WAIUKU to AUCKLAND

TESTED BY: I MORAR - R KWAN DATE: 01/03/94 JOB No: 39099.00

PAVEMENT DESCRIPTION

SEAL: Chipseal ASPHALTIC CONC. TEMP.: - °C DEPTH TEMP. RECORDED: mm TIME: A.M.

BASECOURSE: SUB BASE:

S.I.M.: SUBGRADE:

AXLE LOAD: 8.33 Tonnes TYRE PRESSURE: 520 kPa TYRE PRESSURE GAUGE No: FTS11-1

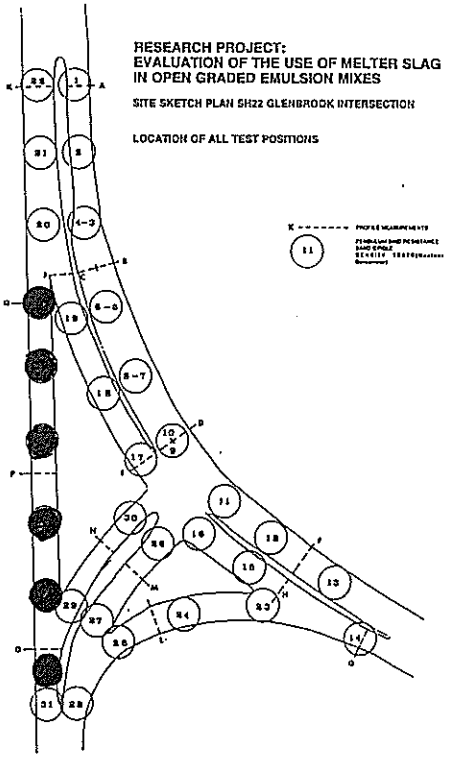
BEAM No: 4 DIAL GAUGE No: S30

Folio No: FS/94/41 Test No: 1827

Sheet 3 of 6

Distance (Metres)	FAST LANE (REBOUND DEFLECTIONS (mm))		Distance (Metres)	SLOW LANE (REBOUND DEFLECTIONS (mm))	
	Outer wheel	Inner wheel		Inner Wheel	Outer wheel
0	0.97	0.56			
20	0.64	0.30			
40	0.38	0.61			
60	0.44	0.40			
80	0.34	0.46			
100	0.34	0.74			

REMARKS



STATISTICAL ANALYSIS OF TEST DATA

NUMBER OF TESTS:	12
AVERAGE REBOUND DEFLECTION:	0.52mm
STANDARD DEVIATION:	0.19
COEFFICIENT OF VARIATION:	36.8%
95 PERCENTILE:	0.81mm

CHECKED BY: S Kaukas DATE: 14/03/94

APPROVED SIGNATORY: C Harrison

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AUCKLAND ENGINEERING LABORATORY
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Phone 0-9-309 6863, Fax 0-9-303 4470

BENKELMAN BEAM - TEST SHEET

Tested in accordance with NRB T/1 1977 (Modified)

JOB NAME: OGEM TRIALS - STATE HIGHWAY 22 Ref PR3-0112

LOCATION: PUKEKOHE to DRURY (Decreasing Lane)

TESTED BY: I MORAR DATE: 01/03/94 JOB No: 39099.00

PAVEMENT DESCRIPTION

SEAL: Chipseal ASPHALTIC CONC. TEMP.: - °C DEPTH TEMP. RECORDED: mm TIME: A.M.

BASECOURSE: SUB BASE:

S.I.M.: SUBGRADE:

AXLE LOAD: 8.33 Tonnes TYRE PRESSURE: 520 kPa TYRE PRESSURE GAUGE No: FTS11-1

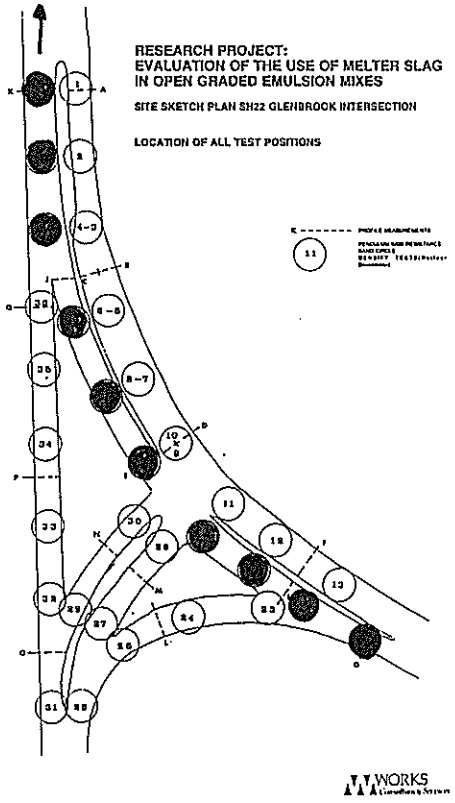
BEAM No: 4 DIAL GAUGE No: S30

Folio No: FS/94/41 Test No: 1828

Sheet 4 of 6

Distance (Metres)	FAST LANE [REBOUND DEFLECTIONS (mm)]		Distance (Metres)	SLOW LANE [REBOUND DEFLECTIONS (mm)]	
	Outer wheel	Inner wheel		Inner Wheel	Outer wheel
0	0.38	0.50			
20	0.50	0.56			
40	0.44	0.44			
60	0.36	0.28			
80	1.14	0.16			
100	0.46	0.24			
120	0.60	0.16			
140	0.52	0.58			
160	0.22	0.42			
180	0.46	0.64			

REMARKS



STATISTICAL ANALYSIS OF TEST DATA

NUMBER OF TESTS:	20
AVERAGE REBOUND DEFLECTION:	0.45mm
STANDARD DEVIATION:	0.21
COEFFICIENT OF VARIATION:	46.4%
95 PERCENTILE:	0.78mm

CHECKED BY: S Kaukas DATE: 14/03/94

APPROVED SIGNATORY: C Harrison

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AUCKLAND ENGINEERING LABORATORY
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BENKELMAN BEAM - TEST SHEET

Tested in accordance with NRB T/1 1977 (Modified)

JOB NAME: OGEM TRIALS - STATE HIGHWAY 22 Ref PR3-0112

LOCATION: PUKEKOHE to DRURY (Increasing Lane)

TESTED BY: I MORAR DATE: 01/03/94 JOB No: 39099.00

PAVEMENT DESCRIPTION

SEAL: Chipseal ASPHALTIC CONC. TEMP.: - °C DEPTH TEMP. RECORDED: mm TIME: A.M.

BASECOURSE: SUB BASE:

S.I.M.: SUBGRADE:

AXLE LOAD: 8.33 Tonnes TYRE PRESSURE: 520 kPa TYRE PRESSURE GAUGE No: FTS11-1

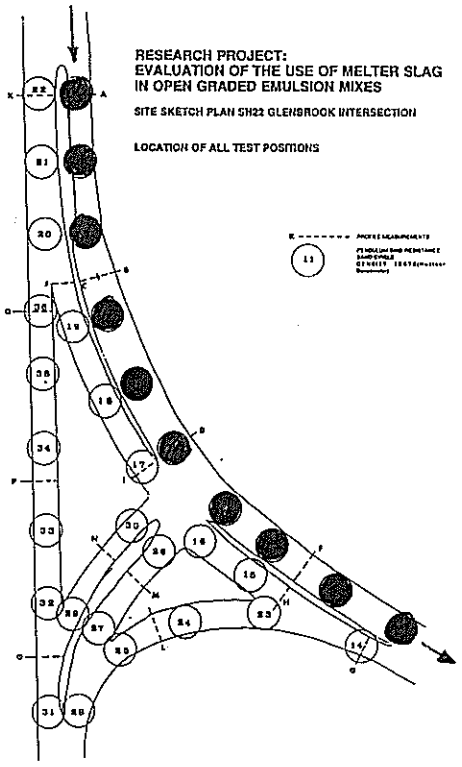
BEAM No: 4 DIAL GAUGE No: S30

Distance (Metres)	FAST LANE [REBOUND DEFLECTIONS (mm)]		Distance (Metres)	SLOW LANE [REBOUND DEFLECTIONS (mm)]	
	Outer wheel	Inner wheel		Inner Wheel	Outer wheel
0	0.56	0.46			
20	0.44	0.56			
40	0.24	0.20			
60	0.28	0.22			
80	0.30	0.16			
100	0.38	0.26			
120	0.34	0.20			
140	0.26	0.18			
160	0.24	0.20			

Folio No: FS/94/41 Test No: 1829

Sheet 5 of 6

REMARKS



STATISTICAL ANALYSIS OF TEST DATA

NUMBER OF TESTS:	18
AVERAGE REBOUND DEFLECTION:	0.30mm
STANDARD DEVIATION:	0.12
COEFFICIENT OF VARIATION:	40.14%
95 PERCENTILE:	0.49mm

CHECKED BY: S Kaukas DATE: 14/03/94

APPROVED SIGNATORY: C Harrison

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BENKELMAN BEAM - TEST SHEET

Tested in accordance with NRB T/1 1977 (Modified)

JOB NAME: OGEM TRIALS - STATE HIGHWAY 22 Ref PR3-0112

LOCATION: RIGHT TURN LANE SH22 - GLENBROOK ROAD

TESTED BY: I MORAR DATE: 01/03/94 JOB No: 39099.00

PAVEMENT DESCRIPTION

SEAL: Chipseal ASPHALTIC CONC. TEMP.: - °C DEPTH TEMP. RECORDED: mm TIME: A.M.

BASECOURSE: SUB BASE:

S.I.M.: SUBGRADE:

AXLE LOAD: 8.33 Tonnes TYRE PRESSURE: 520 kPa TYRE PRESSURE GAUGE No: FTS11-1

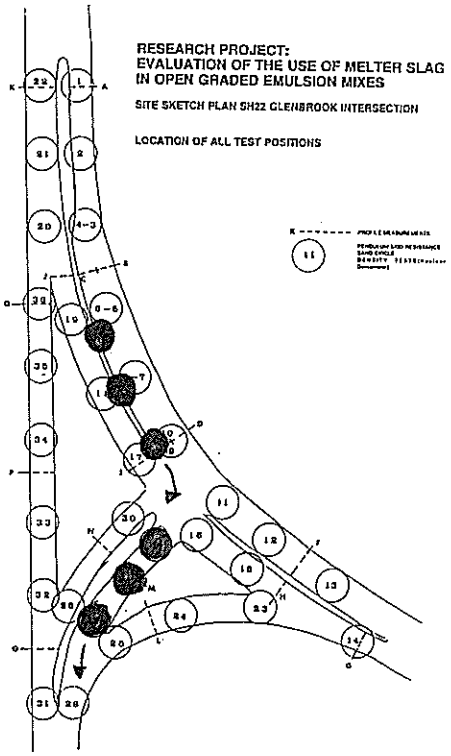
BEAM No: 4 DIAL GAUGE No: S30

Folio No: FS/94/41 Test No: 1830/31

Sheet 6 of 6

Distance (Metres)	FAST LANE [REBOUND DEFLECTIONS (mm)]		Distance (Metres)	SLOW LANE [REBOUND DEFLECTIONS (mm)]	
	Outer wheel	Inner wheel		Inner Wheel	Outer wheel
	SH22 Right				
0	0.42	0.22			
20	0.38	0.28			
40	0.42	0.30			
Test 1831	Glenbrook Road				
0	0.54	0.30			
20	0.76	0.40			
40	0.36	0.36			

REMARKS



STATISTICAL ANALYSIS OF TEST DATA

NUMBER OF TESTS:	12
AVERAGE REBOUND DEFLECTION:	0.40mm
STANDARD DEVIATION:	0.14
COEFFICIENT OF VARIATION:	34.30%
95 PERCENTILE:	0.60mm

CHECKED BY: S Kaukas DATE: 14/03/94

APPROVED SIGNATORY: C Harrison

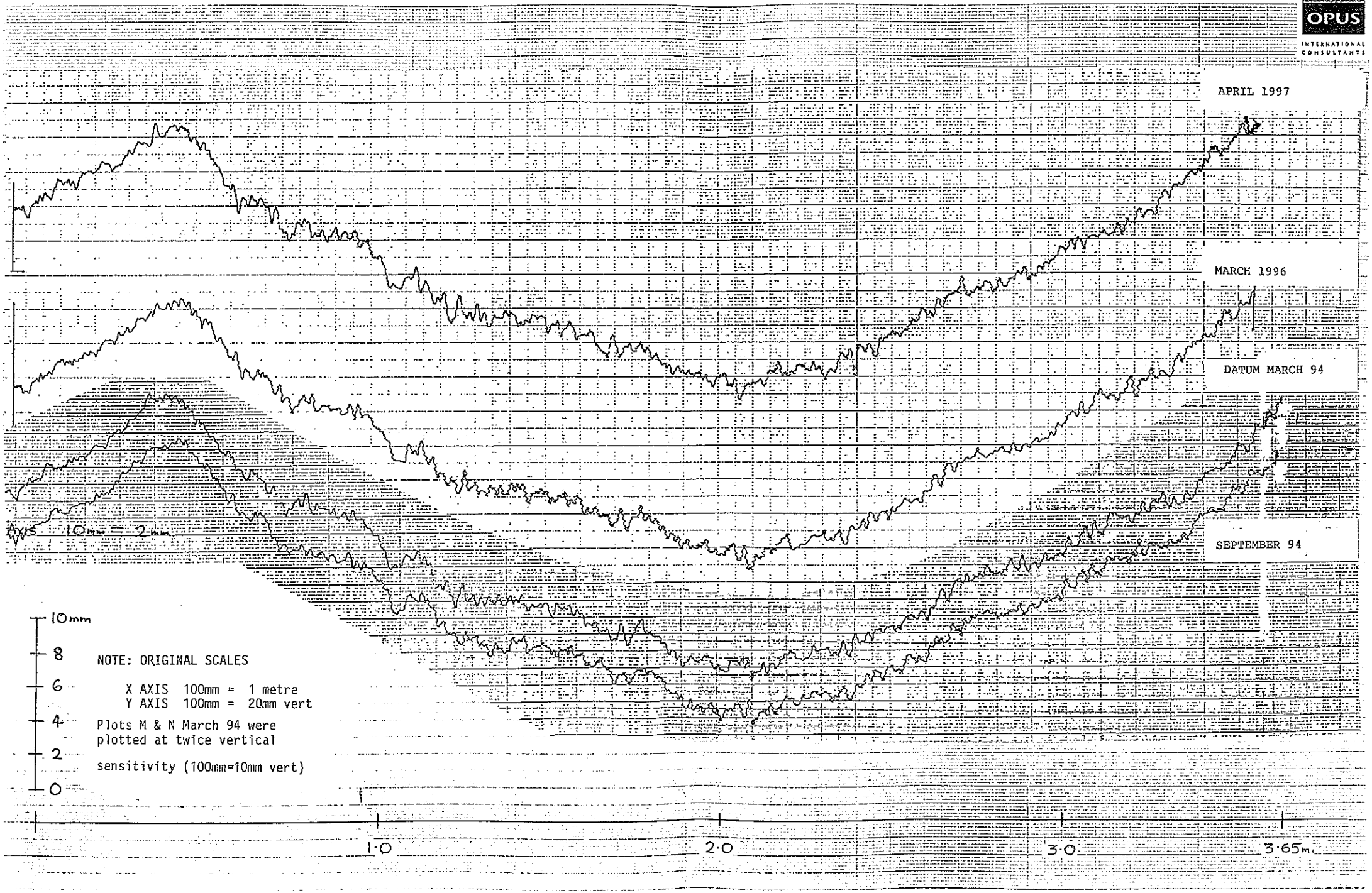
TELARC

APPENDIX 2
TRANSVERSE ROAD PROFILE RESULTS

TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: **A**
Date:

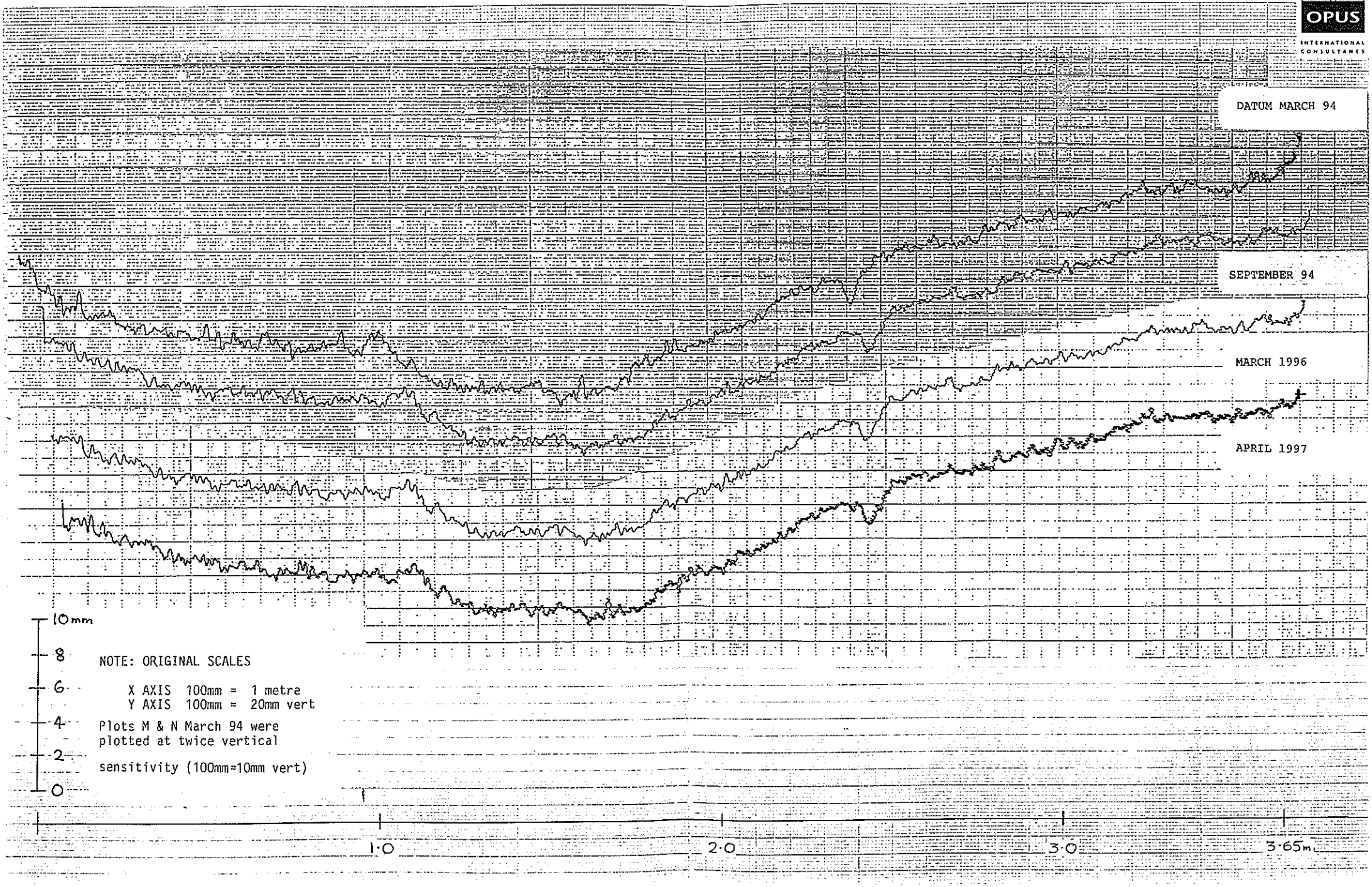
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: B
Date:

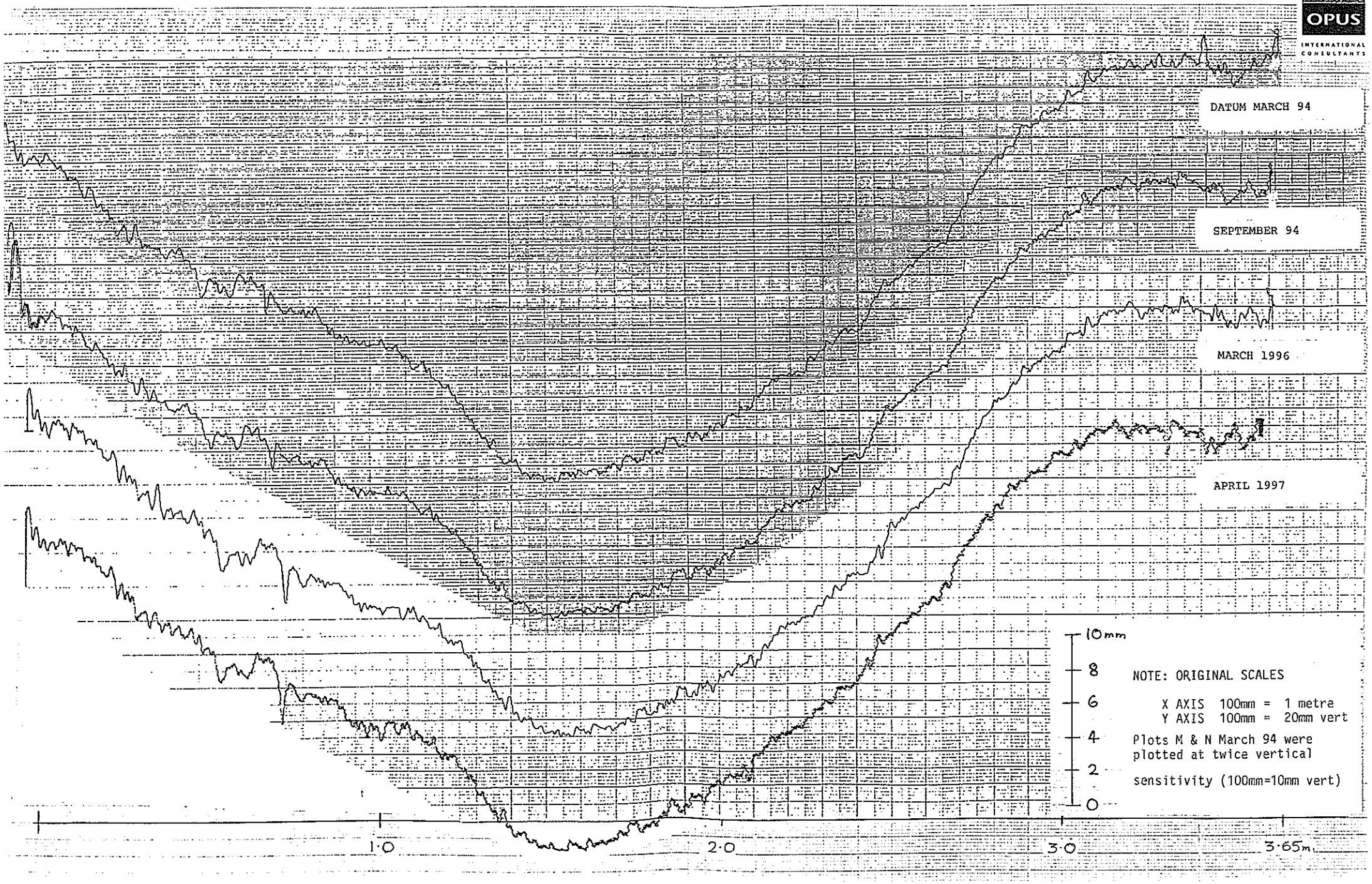
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: **c**
Date:

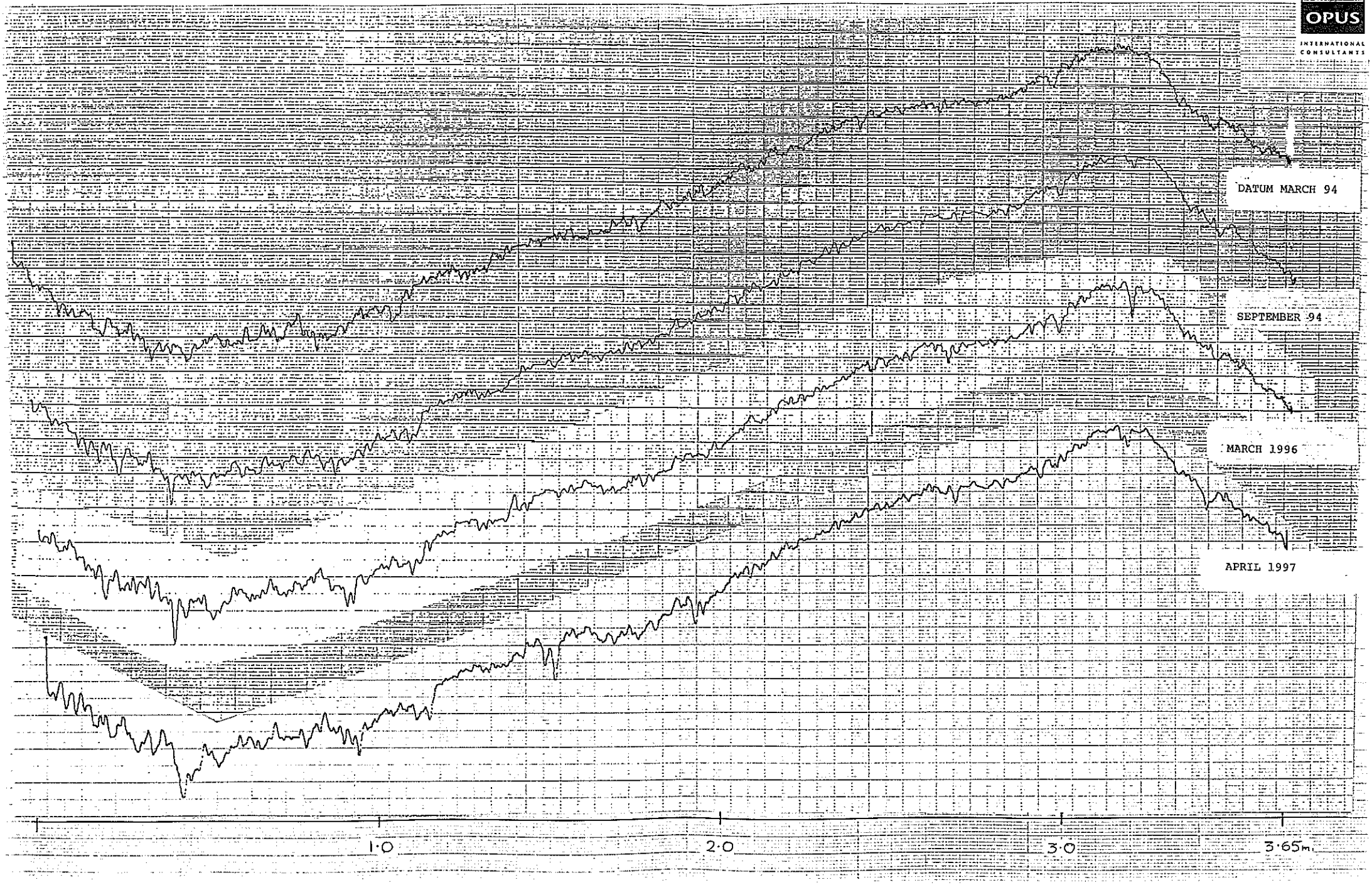
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: D
Date:

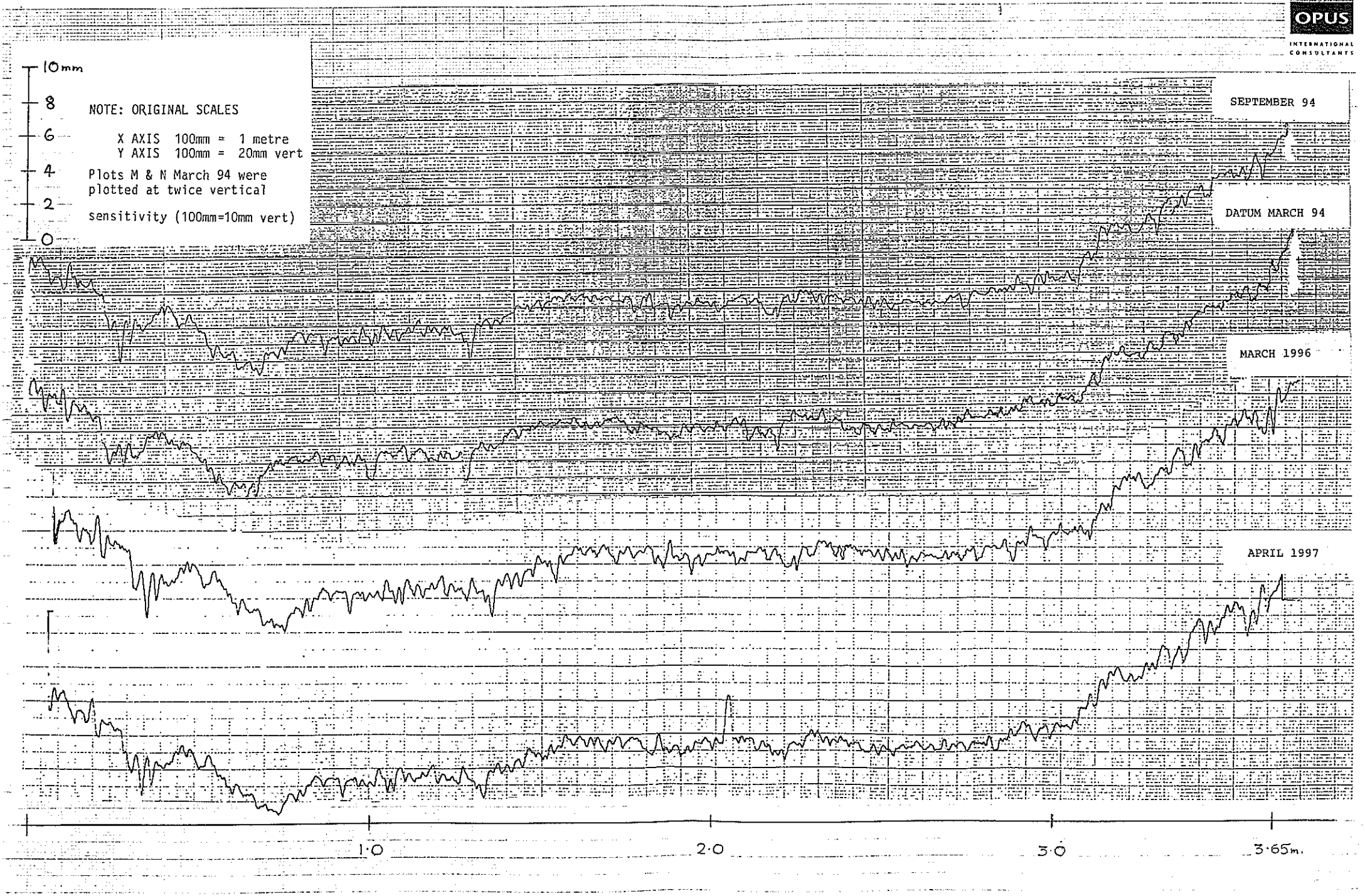
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: E
Date:

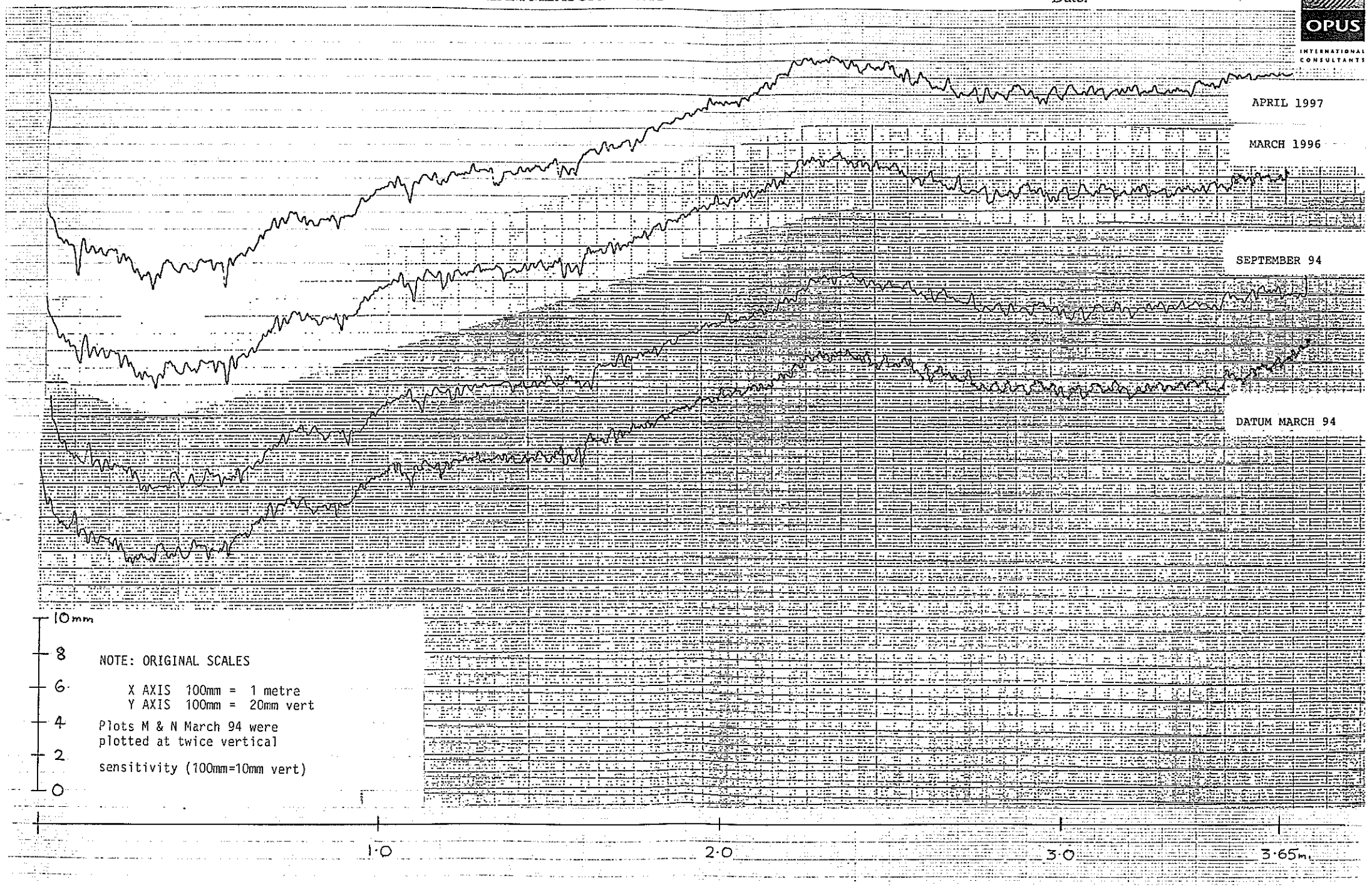
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: F
Date:

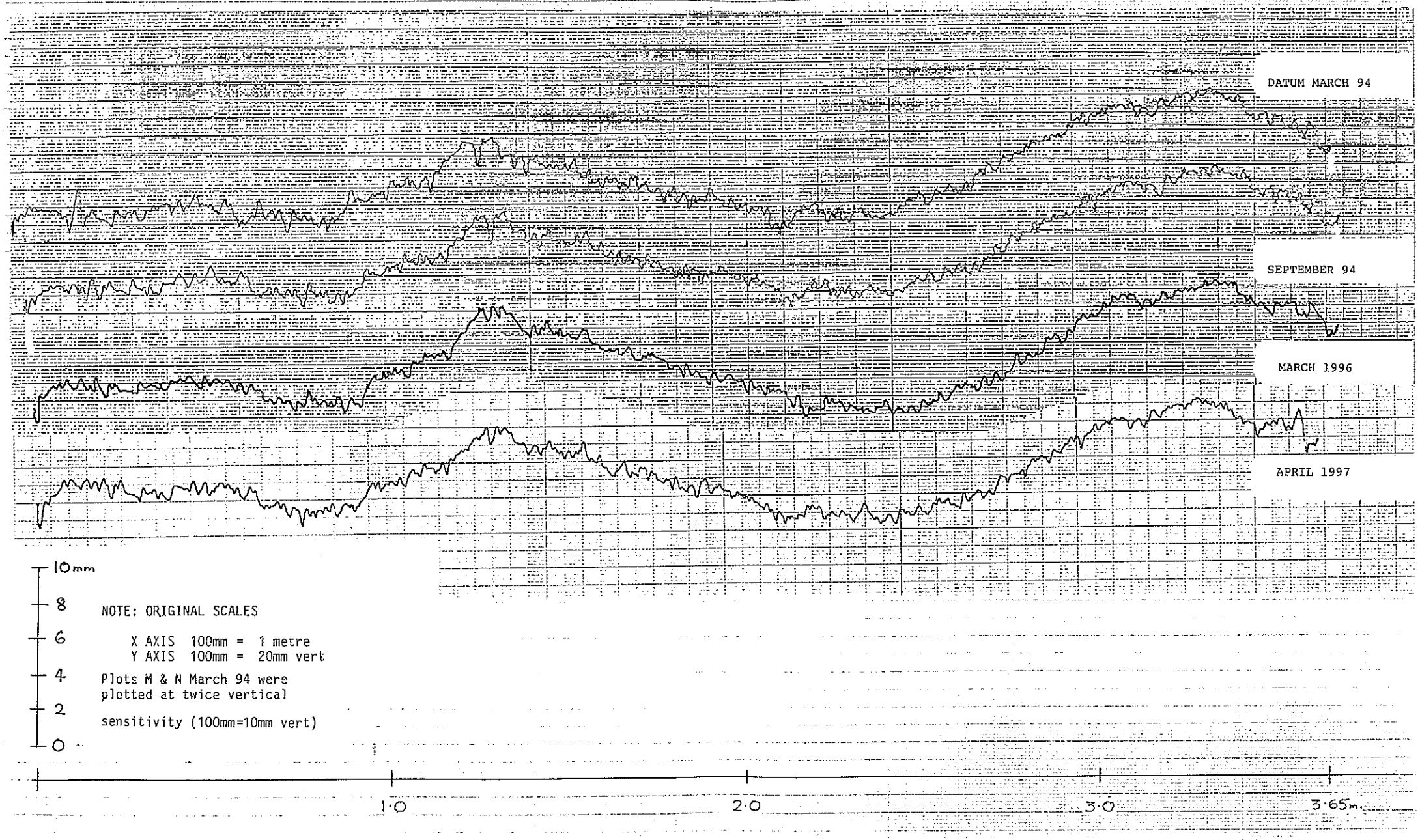
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: G
Date:

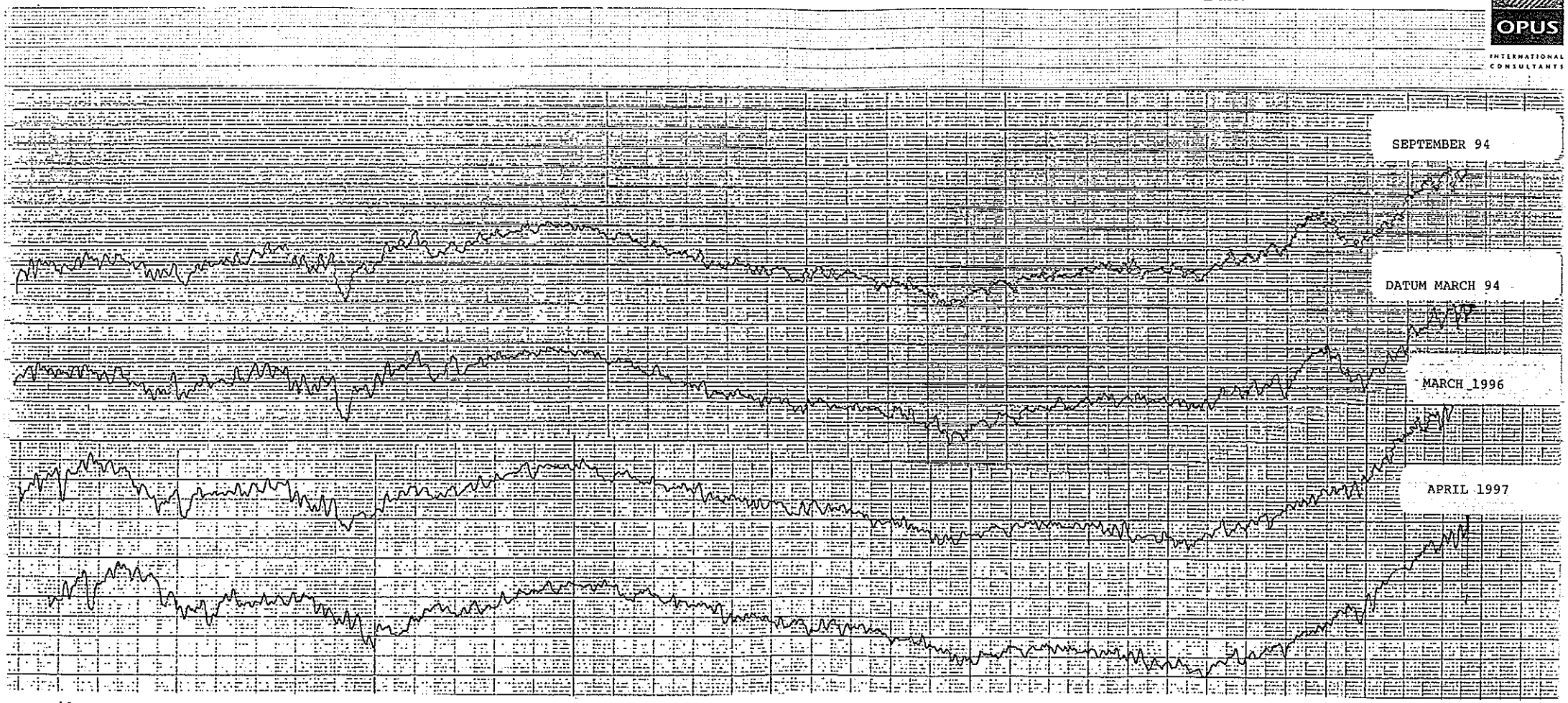
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: H
Date:

OPUS INTERNATIONAL CONSULTANTS



10mm
8
6
4
2
0

NOTE: ORIGINAL SCALES

X AXIS 100mm = 1 metre
Y AXIS 100mm = 20mm vert

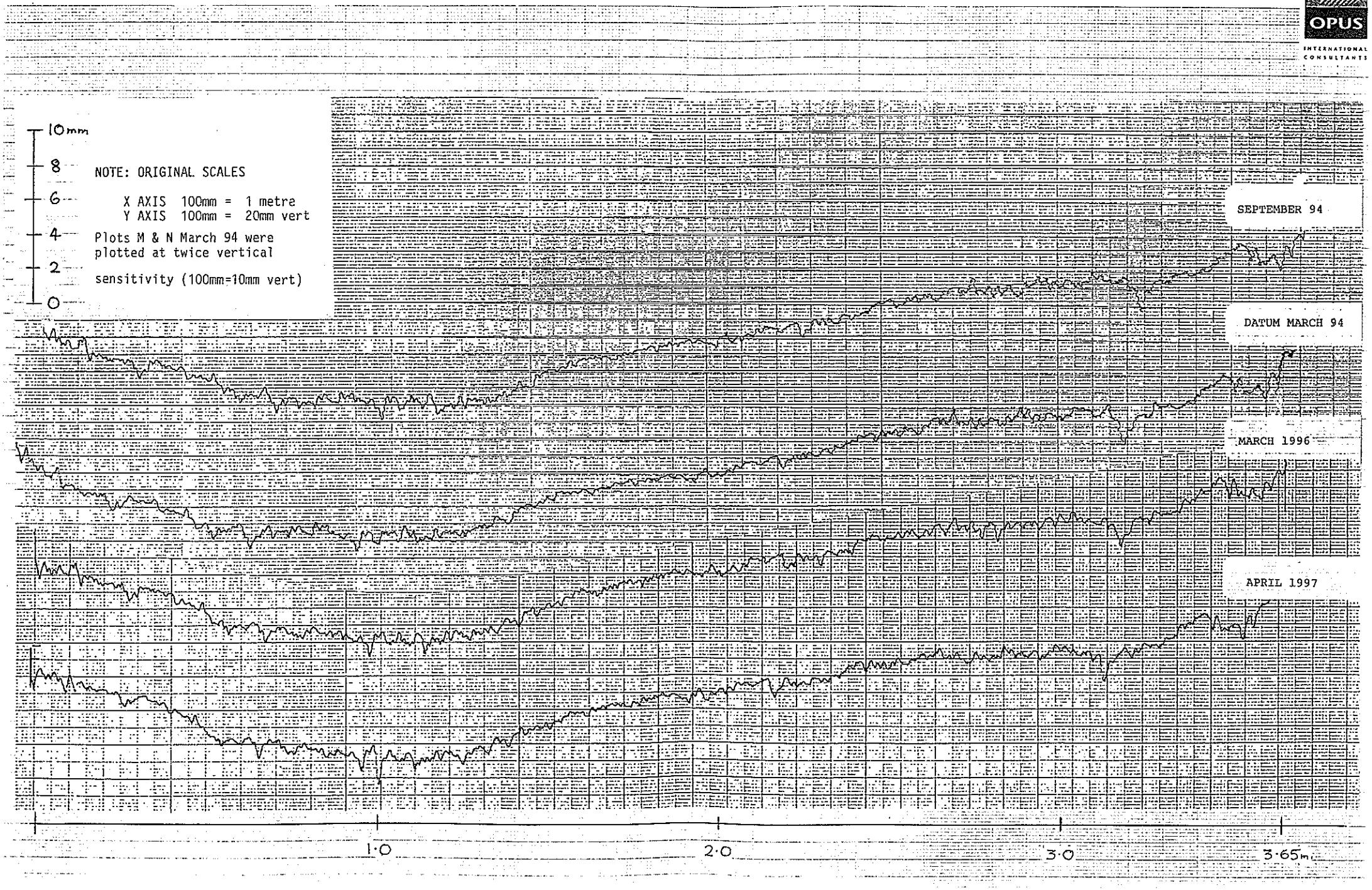
Plots M & N March 94 were plotted at twice vertical sensitivity (100mm=10mm vert)

1·0 2·0 3·0 3·65m

TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: 1
Date:

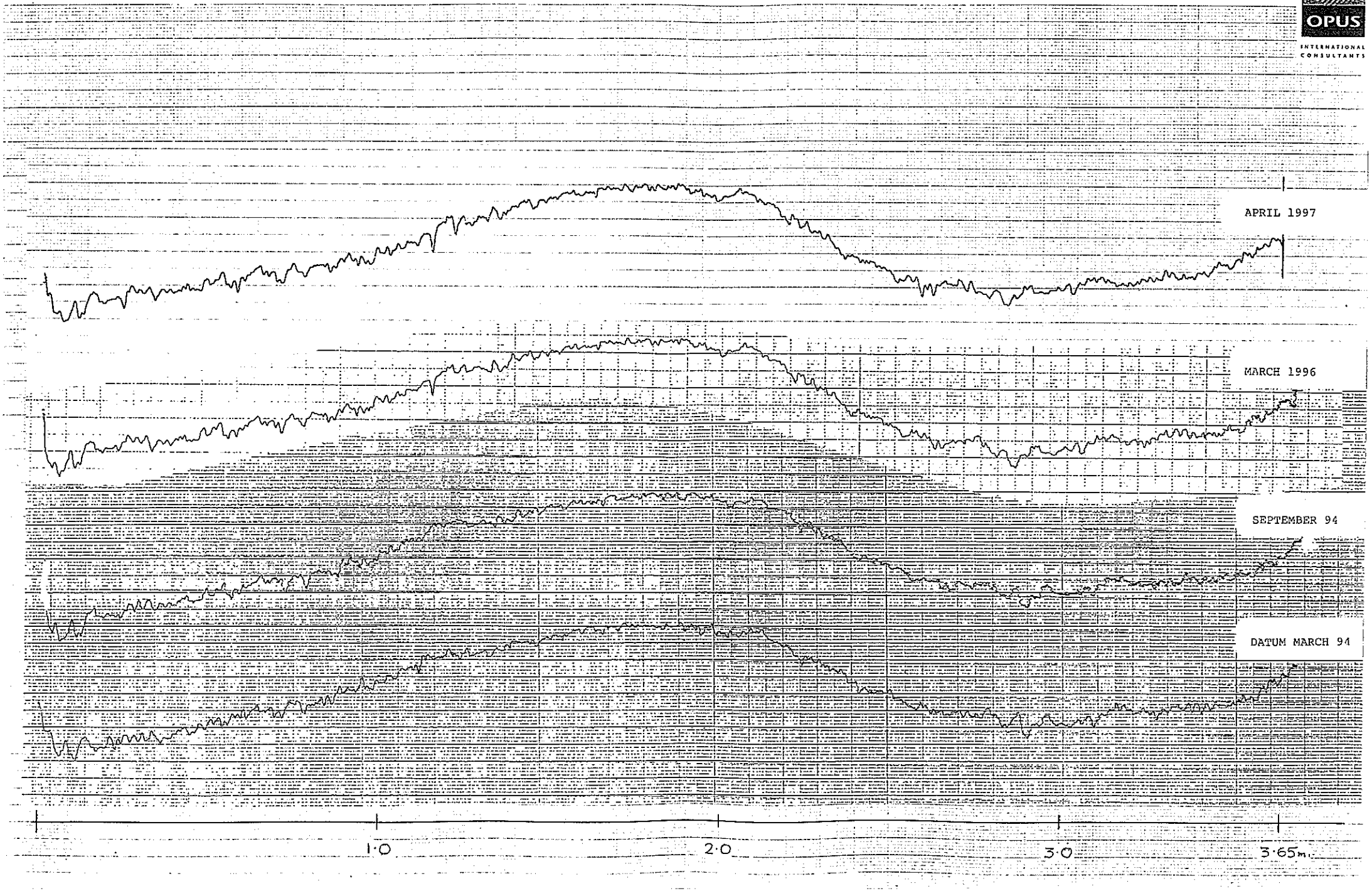
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: J
Date:

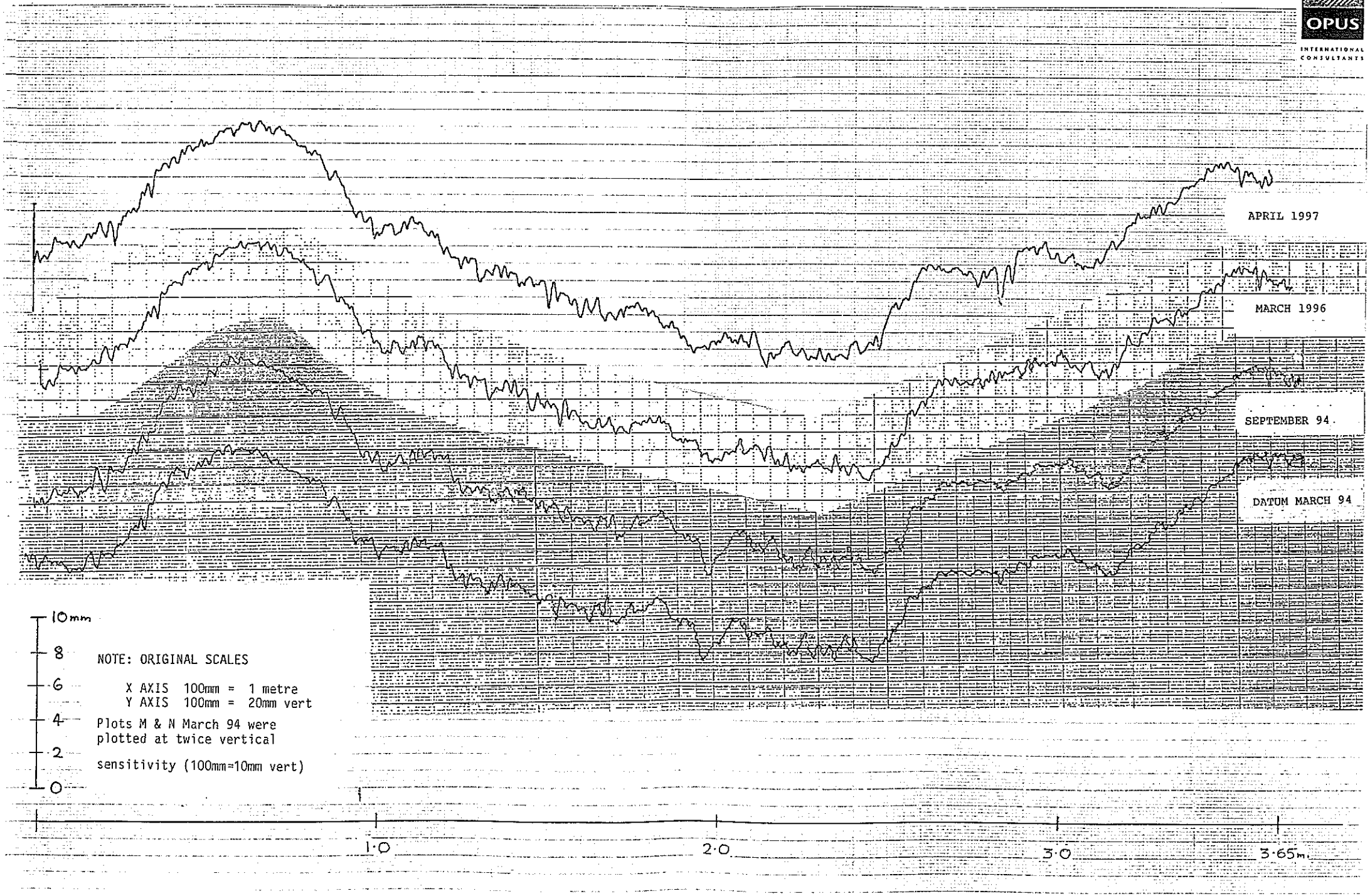
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: K
Date:

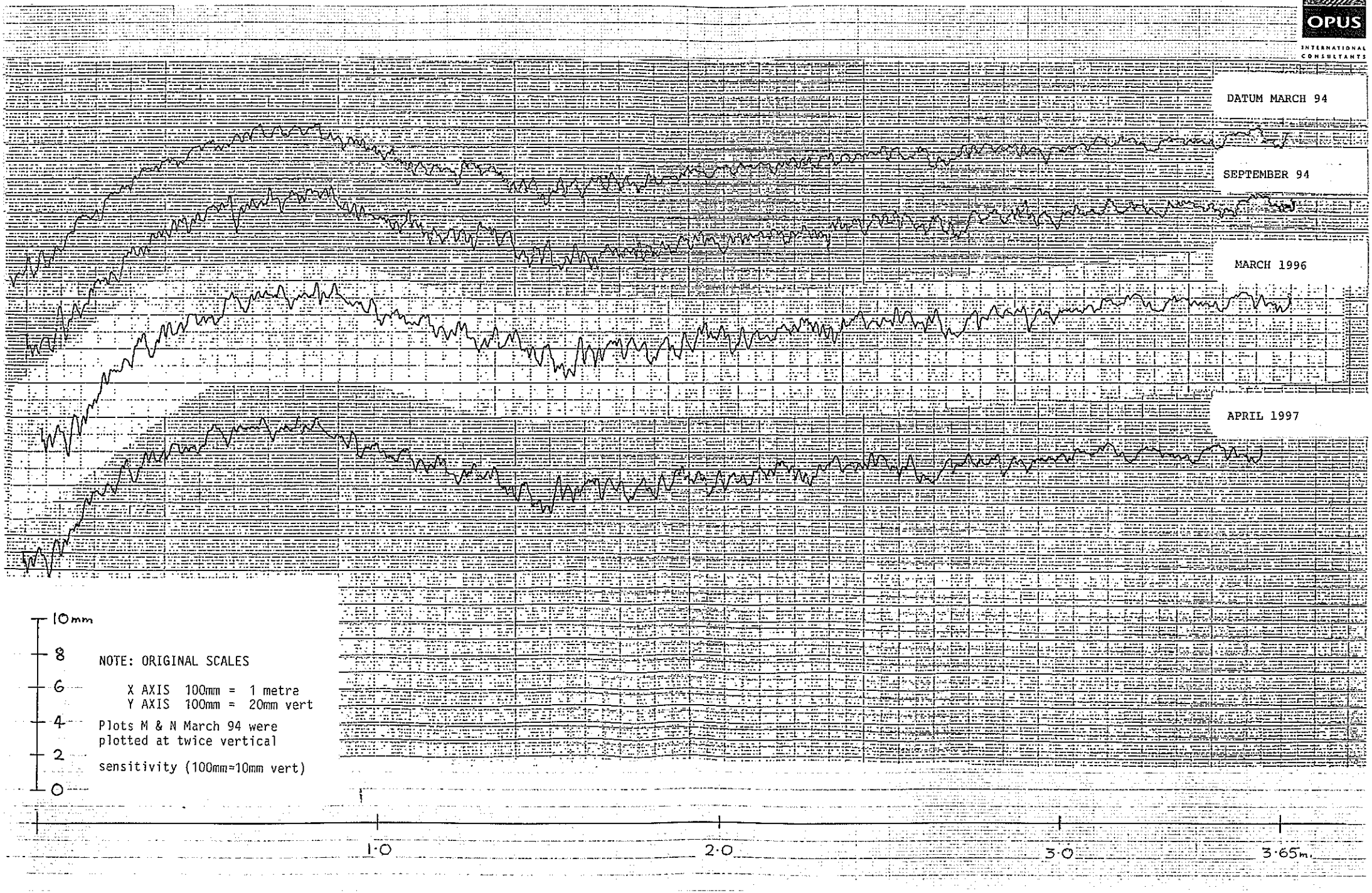
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: L
Date:

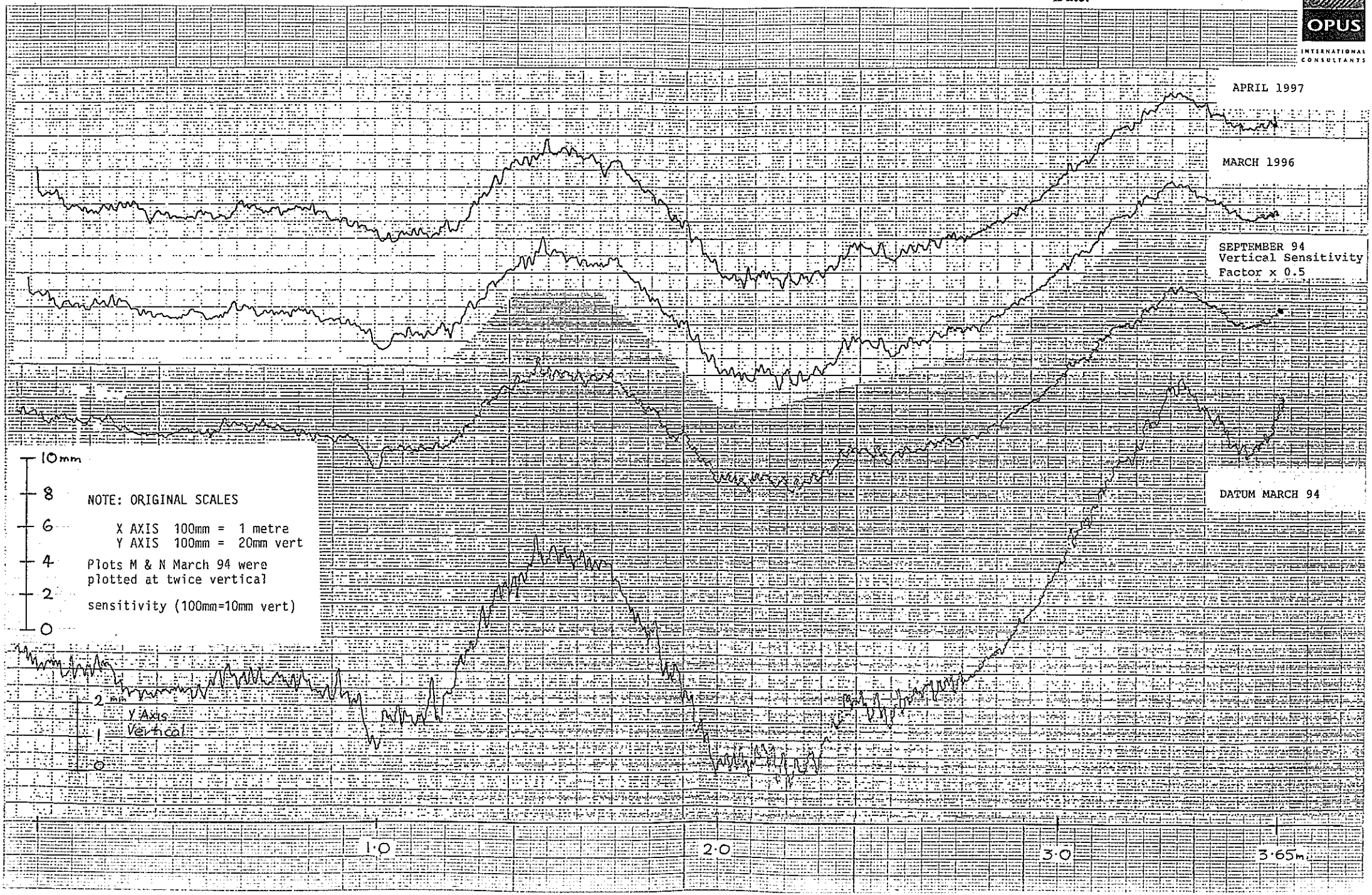
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: M
Date: -

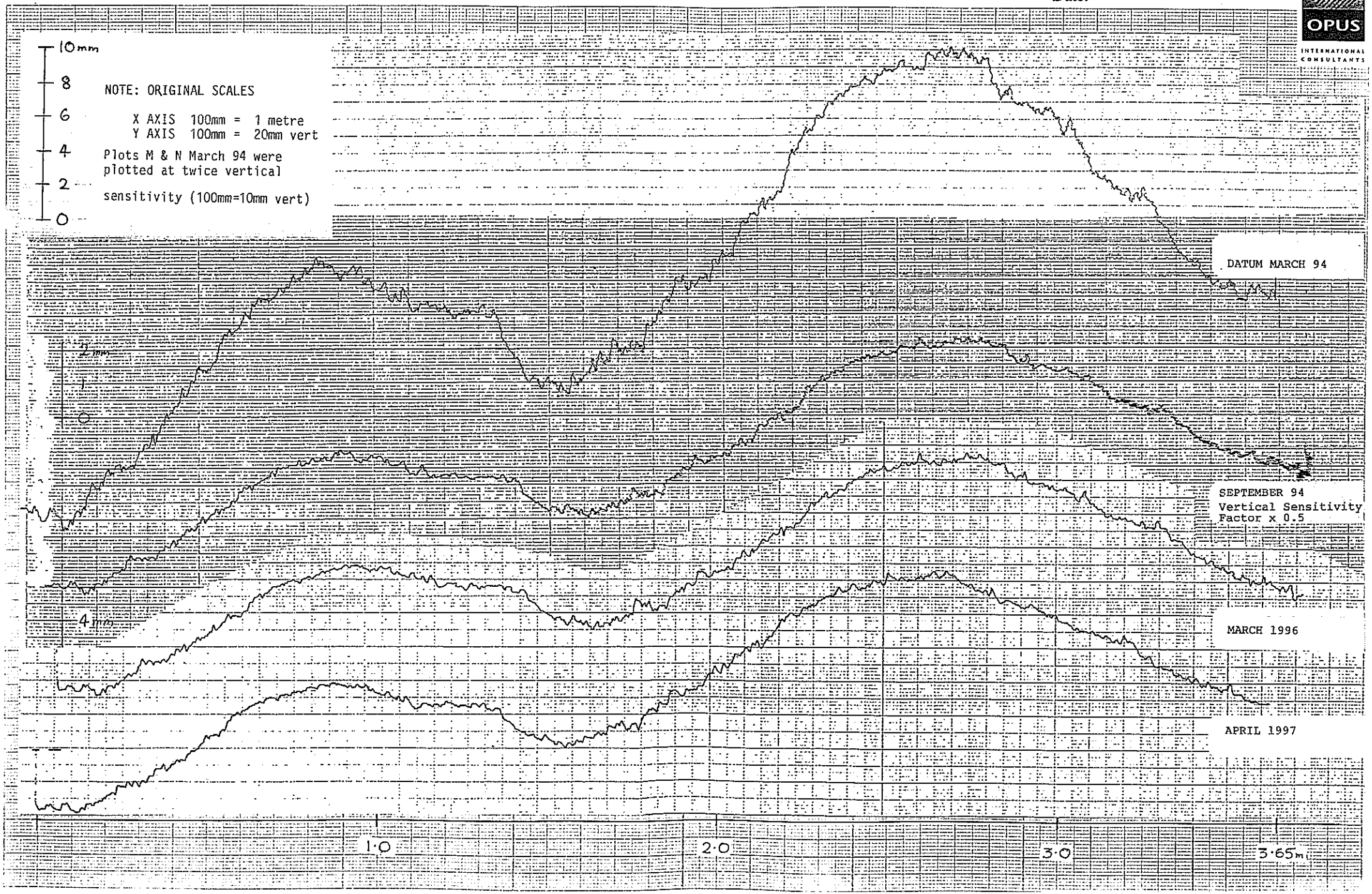
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: **N**
Date:

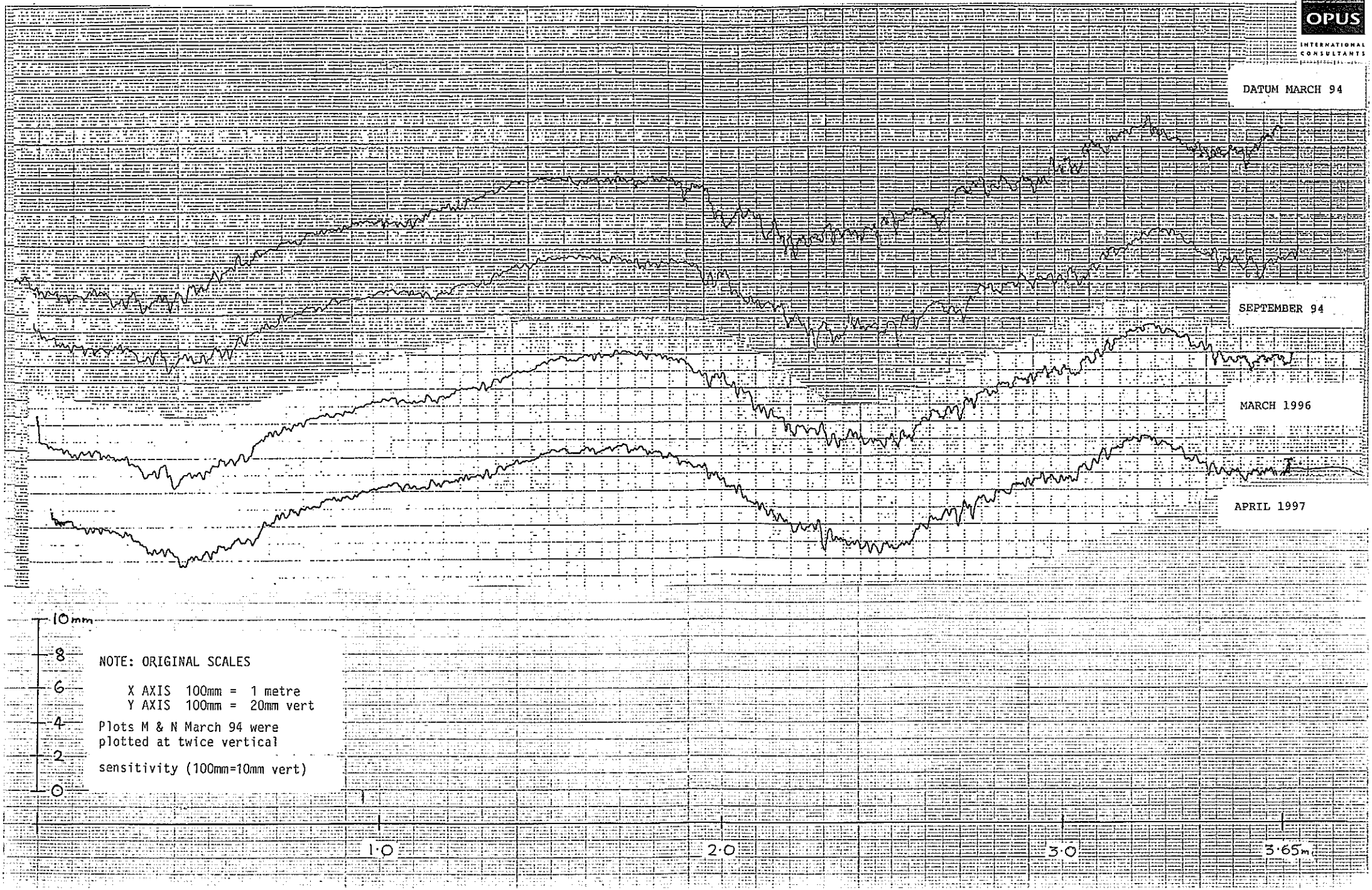
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: o
Date:

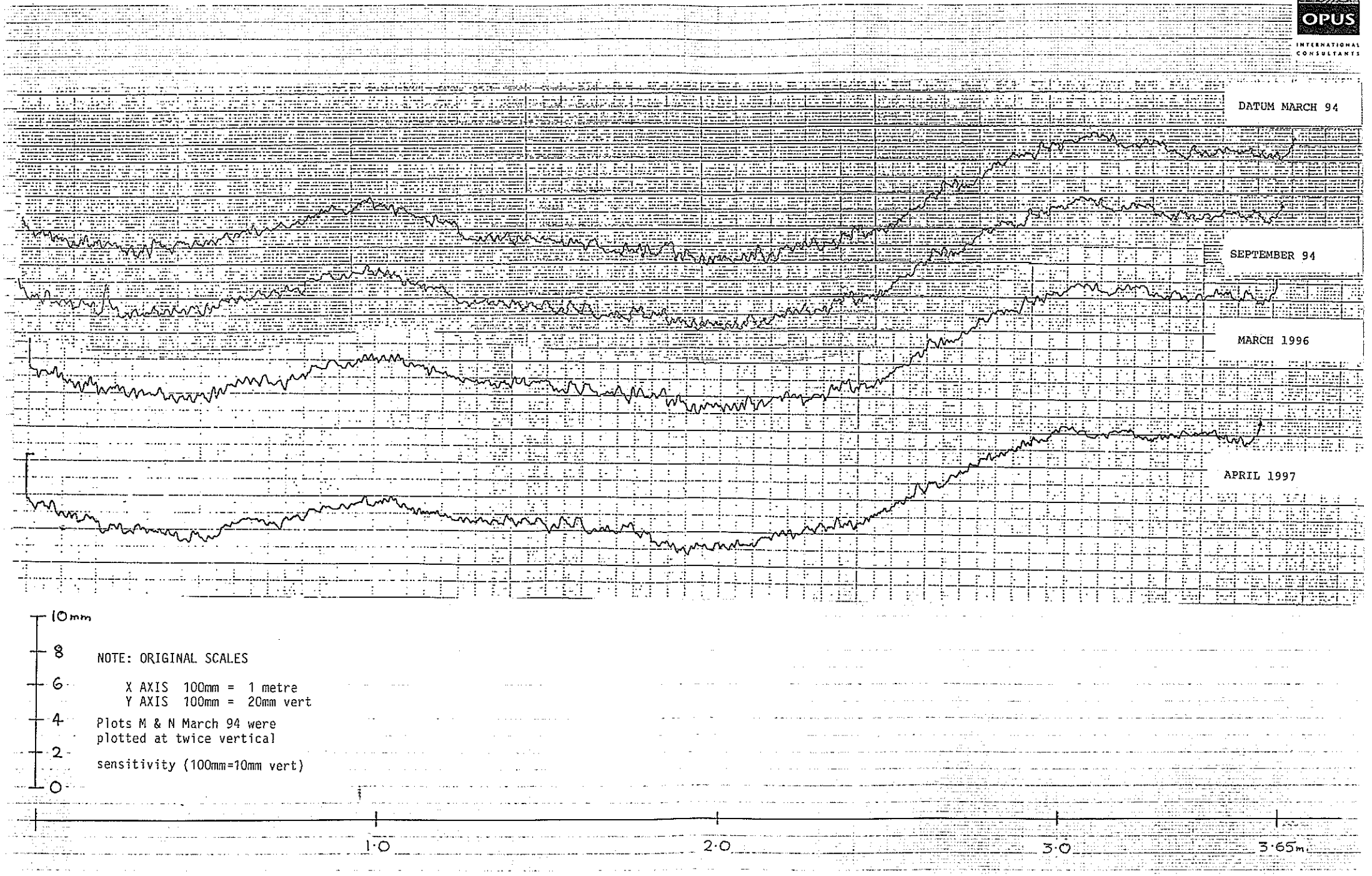
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: **P**
Date:

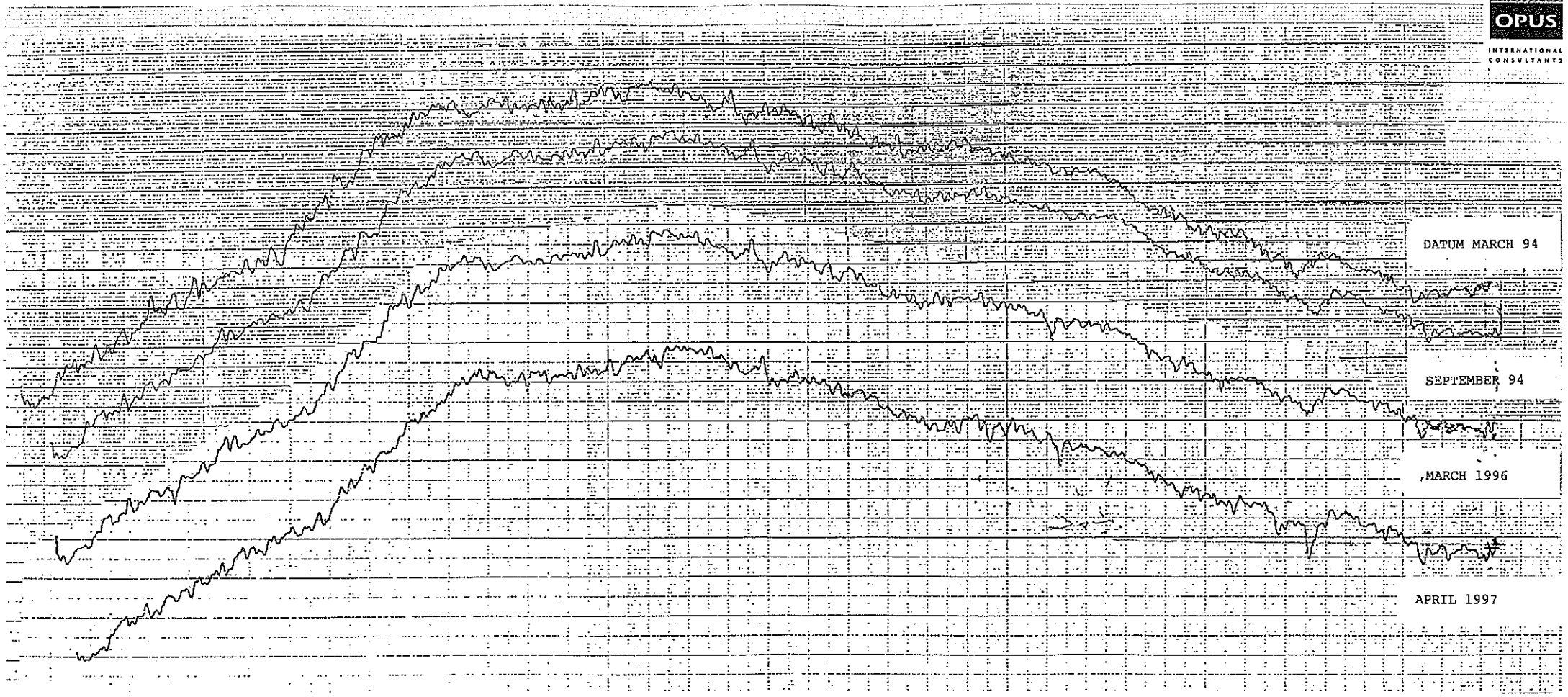
OPUS INTERNATIONAL CONSULTANTS



TRANSIT NEW ZEALAND RESEARCH PROJECT PR3-0112 (SH22)
Evaluation of the use of Melter Slag in Open Graded Emulsion Mixes "OGEM"
PROFILE BEAM MEASUREMENTS

Site No: Q
Date:

OPUS INTERNATIONAL CONSULTANTS



10mm
8
6
4
2
0

NOTE: ORIGINAL SCALES

X AXIS 100mm = 1 metre
Y AXIS 100mm = 20mm vert

Plots M & N March 94 were plotted at twice vertical sensitivity (100mm=10mm vert)

1·0 2·0 3·0 3·65m

APPENDIX 3
MATERIALS TESTS RESULTS

Lab No. A94/100
Date 20/01/94

Tested By
Date 21/1/94
Checked By

BITUMIX AUCKLAND

MIX DESIGN Mix 2 (Emopatch) Jan-94

Lab No		A94/089	A94/088			
Sieve		Pap 3	Grade 5		Mix	WAK 11
Size		40	60		Design	Spec.
26.5mm		100	100		100.0	100-100
19.0mm		100	100		100.0	100-100
13.2mm		100	100		100.0	100-100
9.53mm		100	100		100.0	90-100
4.75mm		100	3		41.8	30-50
2.36mm		93	0.4		37.4	
1.18mm		50	0.4		20.2	10-30
600um		29	0.4		11.8	
300um		17.7	0.3		7.3	5-10
150um		10.4	0.3		4.3	
75um		5.5	0.3		2.4	0-5

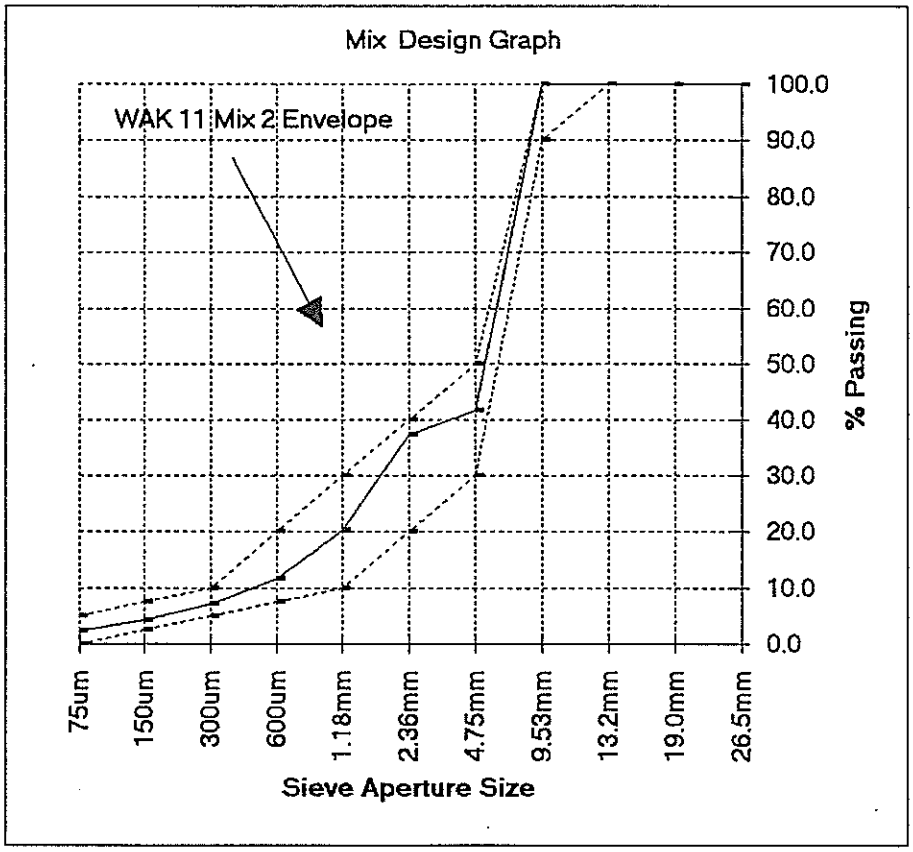
SMF LIMITS

36 – 48

14 – 26

4 – 10

0 – 5



Bitumen Content = 3.5 % (using CM60/200 Emulsion)

		WAK 11 : 1991
Stability @ 60 °C	5.4 kN	2.0 kN min
Flow @ 60°C	1.7mm	N/A
Air Voids	16.50%	N/A
Bulk Density	2.425 t/m³	N/A

Lab No. A94/101
Date 20/01/94

Tested By
Date 21/1/94
Checked By

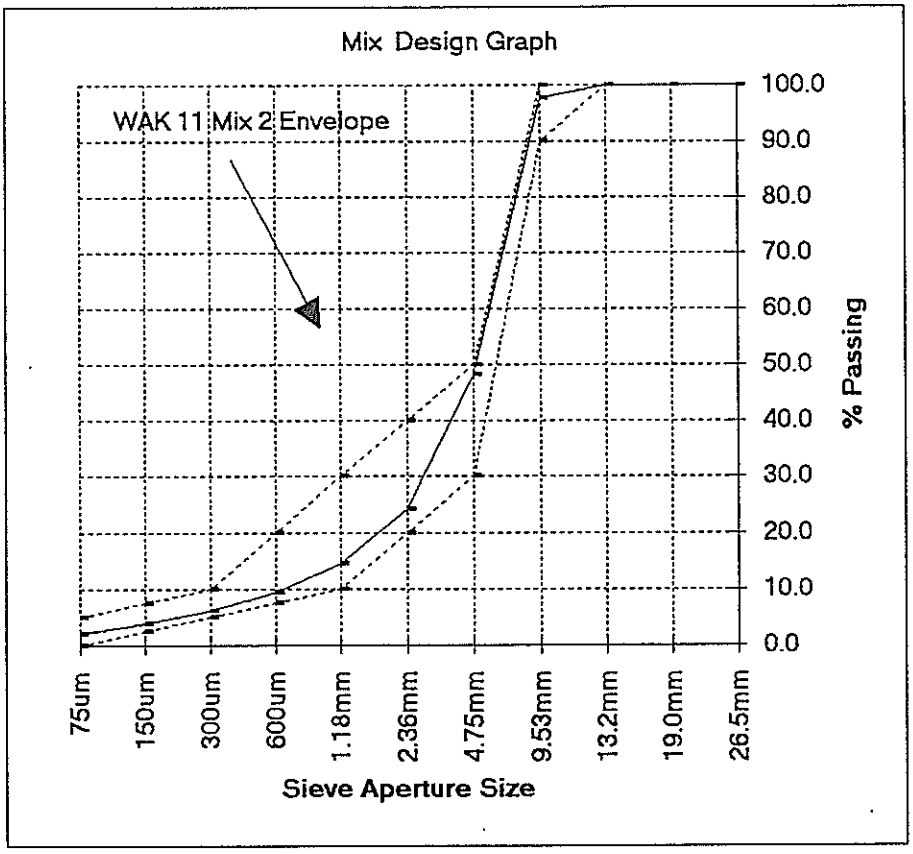
BITUMIX AUCKLAND

MIX DESIGN Mix 2 (Pavore) Jan-94

Lab No		B93/2633	B93/1123			
Sieve		10/5	GAP 7		Mix	WAK 11
Size		55	45		Design	Spec.
26.5mm		100	100		100.0	100-100
19.0mm		100	100		100.0	100-100
13.2mm		100	100		100.0	100-100
9.53mm		96	100		97.8	90-100
4.75mm		26.1	75.7		48.4	30-50
2.36mm		6.3	46.1		24.2	
1.18mm		3	28.8		14.6	10-30
600um		1.7	18.9		9.4	
300um		1.2	12.2		6.2	5-10
150um		0.8	7.7		3.9	
75um		0.4	4.3		2.2	0-5

JMF LIMITS

89 – 100
42 – 54
9 – 21
3 – 9
0 – 5



Bitumen Content = 4.5 % CM60/100 Emulsion

WAK 11 : 1991

Stability @ 60 °C	6.2 kN	2.0 kN min
Flow @ 60°C	2.3mm	N/A
Air Voids	20.80%	N/A
Bulk Density	2.449 t/m³	N/A

Lab No. A94/102
Date 20/01/94

Tested By
Date 21/1/94
Checked By

BITUMIX AUCKLAND

MIX DESIGN Mix 2/3 (Pavore) Jan-94

Lab No			B93/1123			
Sieve			GAP 7		Mix	WAK 11
Size			100		Design	Spec.
26.5mm			100		100.0	100-100
19.0mm			100		100.0	100-100
13.2mm			100		100.0	100-100
9.53mm			100		100.0	90-100
4.75mm			75.7		75.7	30-50
2.36mm			46.1		46.1	
1.18mm			28.8		28.8	10-30
600um			18.9		18.9	
300um			12.2		12.2	5-10
150um			7.7		7.7	
75um			4.3		4.3	0-5

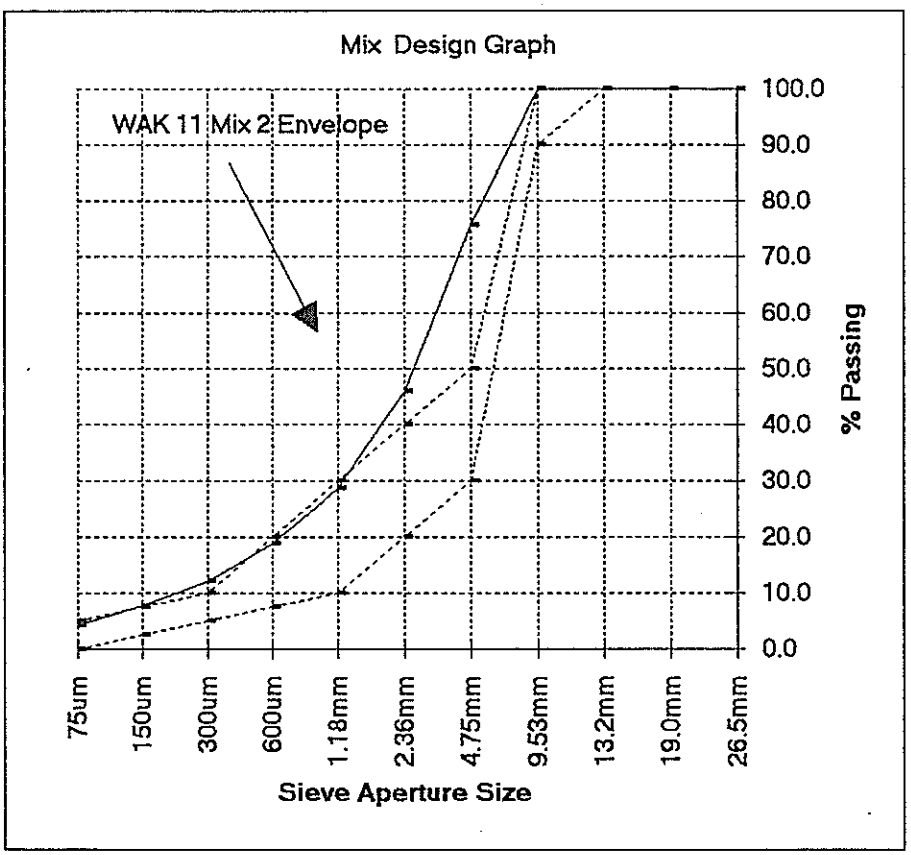
JMF LIMITS

70 – 82

23 – 35

9 – 15

1 – 7



Bitumen Content = 5.0 % CM60/100 Emulsion

		WAK 11 : 1991
Stability @ 60 °C	8.7 kN	2.0 kN min
Flow @ 60°C	2.1mm	N/A
Air Voids	21.20%	N/A
Bulk Density	2.439 t/m³	N/A

STEVENSON

CIVIL ENGINEERING LABORATORIES
A division of W. Stevenson & Sons Limited

14 SIR WILLIAM AVENUE
P.O. BOX 58024 GREENMOUNT

PHONE 0-9-274 4611
FAX 0-9-274 4545

Report Number: 2283T

TEST REPORT

Test Number: B210

Date of issue: 7 July 1993

Client: Bitumix Limited

Clients Address: P.O Box 11 204
Ellerslie
AUCKLAND

RECEIVED
13 JUL 1993

Attention: Mr D. Jones

Subject: Weathering Resistance Test

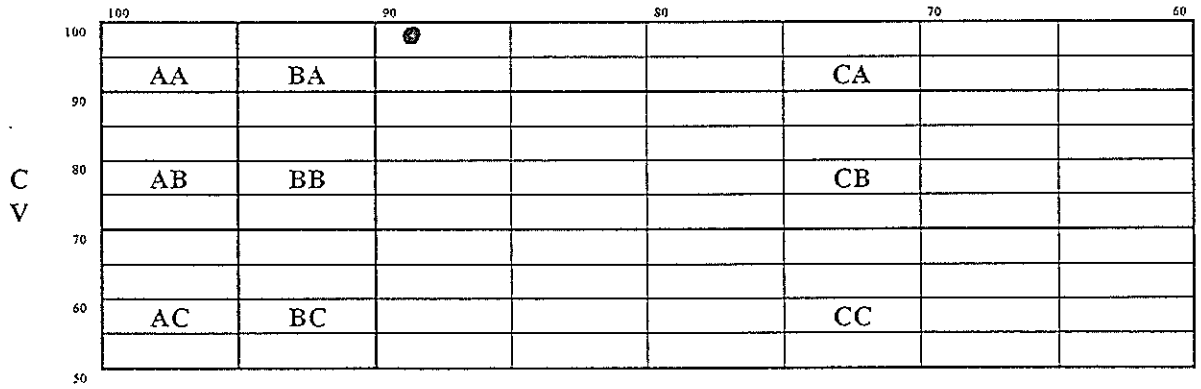
Clients Instructions: Determine the Weathering Resistance of a sample of slag material as delivered to the laboratory.

Test Standards: NZS 3111: 1986: Test 15
Method for determination of weathering resistance of coarse aggregate

TEST RESULTS

Percentage of material retained on a 4.75 mm sieve	88 %
Cleanness Value of aggregate	98
QUALITY INDEX	CA

Percentage retained on a 4.75 mm test sieve



Note: i.

for CIVIL ENGINEERING LABORATORIES

B.T. Beatson
APPROVED SIGNATORY

TELCRC
REGISTERED LABORATORY

ISSUE NO: 1
ISSUE DATE: 10/93

NZS 3111.1986 A 11

Method for Determining Crushing Resistance of Coarse Aggregate

Material: GRADE 2 CHIP. Sample No: A94/047.

Origin: EX SLAG REDUCTION. Date: UNKNOWN (SAMPLE ADVICE NOT SUPPLIED).

TEST:

Maximum Load (kN): 230 KN. (X)

Sample wgt. (g): 2549.3 (9).

Mass passing 2.36mm (g): 552.7 (9).

% Fines passing 2.36 mm: 21.68 (Y)

Load required to produce 10 % fines = $\frac{14X}{Y+4} = \frac{3220.}{25.68.}$

where: (X = maximum load in kilonewtons)
(Y = percentage fines from test at load X)

RESULT:

Crushing Resistance = 125 kN

Comments:

Tested by:

Date: 19/1/94.

Checked by:

CANTERPRISE

UNIVERSITY OF CANTERBURY CHRISTCHURCH NEW ZEALAND

CP/3062

University of Canterbury, Private Bag 4800, Christchurch
Street address: 39 Creyke Road, Christchurch
Telephone 03-366 7001 Direct Line 03-364 2416 Fax 03-364 2069

Bitumix Ltd.
P.O. Box 11204,
Auckland
New Zealand

Dear Mr Burgess,

11-Jun-93

Re : REPORT ON POLISHED STONE VALUE OF SEALING CHIPS

As requested, we have carried out tests of sealing chips in the Highway and Traffic Engineering Laboratory of our Civil Engineering Department to your Order No: 29608

The Polished Stone Value results of the sample provided by your organisation are:

Certificate No. 1993/085

						Specimen Avg.	RAW P.S.V.	Adjusted P.S.V.
Sample	52.8	50.3	50.3	49.4	49.4	49.7		
	57.1	55.4	52.8	52.8	52.0	52.5	50.8	53
NZ STEEL	54.5	52.0	51.1	50.3	50.3	50.5		
	54.5	52.8	51.1	50.3	50.3	50.5		

	52.0	51.1	51.1	50.3	50.3	50.5	
P.S.V.	54.5	51.1	50.3	50.3	49.4	50.0	50.6
Control Stone	55.4	53.7	52.0	52.0	51.1	51.7	
	53.7	52.0	51.1	50.3	49.4	50.3	

Should you have any questions on this report, please contact directly, Mr Bryan Pidwerbesky (03) 364-2237 or Mr David Green (03) 366-7001 ext 7343.
Enclosed is our account for $700-00 (plus $87-50 GST) for carrying out this work, as well as a specimen of the sample after polishing.

We are pleased to have been of assistance to you in carrying out this work and look forward to being of further help to you in the future.

Yours faithfully

D.C. Stevenson
ACTING DIRECTOR
cc Mr D M Green
Mr B D Pidwerbesky

POLISHED STONE VALUE TEST

CERTIFICATE

Certificate Number: 1993/085

Name of Client: Bitumix Ltd.

Quarry Location: NZ STEEL

Material Identification: 10 mm Slag reduction aggregate

This material has been tested to standard BS812:1975, amended 1983, 1989, and the polished stone value determined is: 53

Tested by: D M Sear

Approved by:

Date: 17 / 06 / 19 93

Civil Engineering Laboratories
University of Canterbury
Christchurch

CANTERPRISE
UNIVERSITY OF CANTERBURY CHRISTCHURCH NEW ZEALAND

WORKS Consultancy Services

Auckland Engineering Laboratory
Fansnawe St P.O. Box 5848 Auckland
Ph: 309-6863 Fax: 303-4470

TELARC
THIS LABORATORY IS REGISTERED BY THE TESTING LABORATORY REGISTRATION COUNCIL OF NEW ZEALAND. THE TESTS REPORTED HEREIN HAVE BEEN PERFORMED IN ACCORDANCE WITH ITS TERMS OF REGISTRATION. THIS REPORT MAY NOT BE REPRODUCED EXCEPT IN FULL.

ASPHALTIC CONCRETE RESULT SHEET

Authorised Signatory:

Client: TRANSIT NEW ZEALAND

Contractor: BITUMIX LTD

Job Location: SH 22/GLENBROOK INTERSECTION

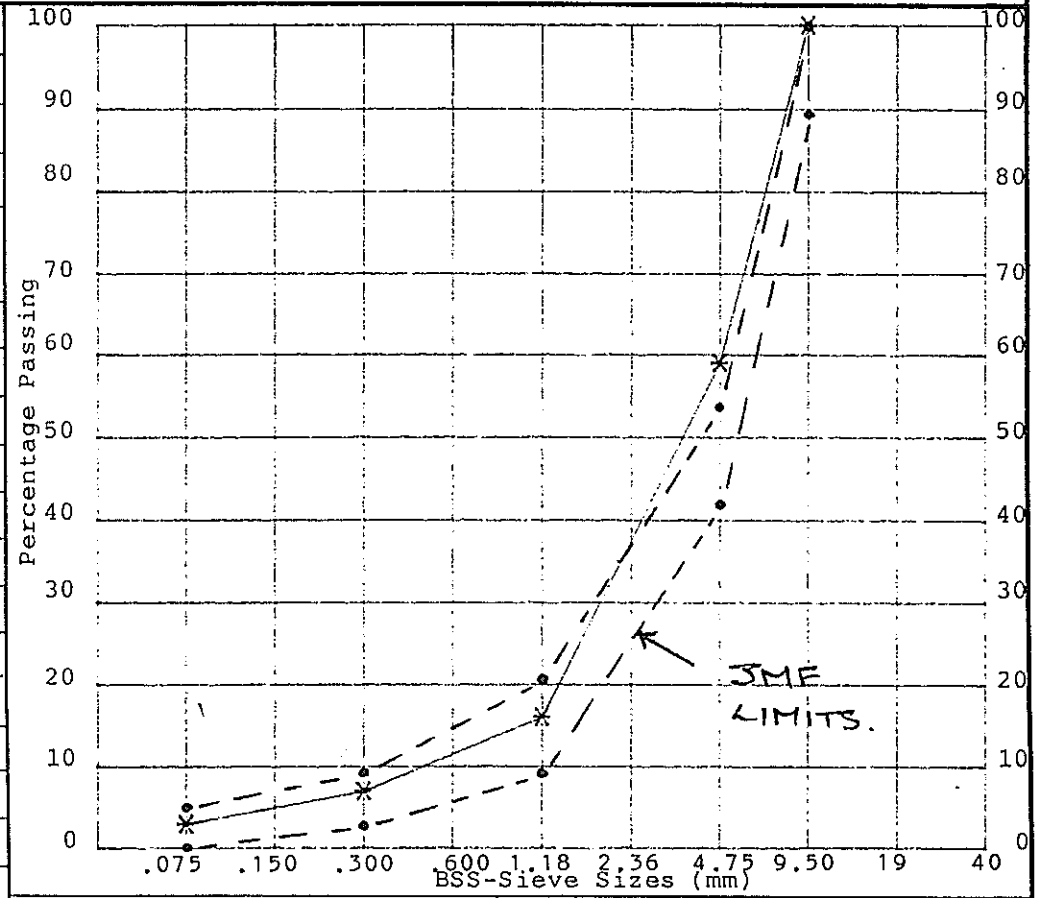
Date Sample Laid: 1/2/94

File No: 5/2

SAMPLE IN ACCORDANCE WITH ASTM D979-89

Sample Description: MIX 2 SLAG

Client Reference		–	
Laboratory Reference		3H/94	
Laboratory Sample No		2	
Mix Temperature on Site (°C)		–	
Sieve Size (BSS)	Job Mix Formula	SIEVE ANALYSIS ASTM C136-84a	
		%Passing	
40.00mm			
19.00mm			
9.50mm	89 – 100	100	
4.75mm	42 – 54	59	
2.36mm			
1.18mm	9 – 21	16	
600µm			
300µm	3 – 9	7	
150µm			
75µm	0 – 5	3	
Graph Symbols			
BITUMEN CONTENT (±0.2%) in Accordance with Test Method ADL 4.02/15a		3.9%	



Tested by: A.A. BROWNE Date: 7/2/94

Checked by: I. J. MURRAY Date: 17/2/94

WORKS Consultancy Services

Auckland Engineering Laboratory
Fanshawe St P.O. Box 5848 Auckland
Ph: 309-6863 Fax: 303-4470

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ASPHALTIC CONCRETE RESULT SHEET

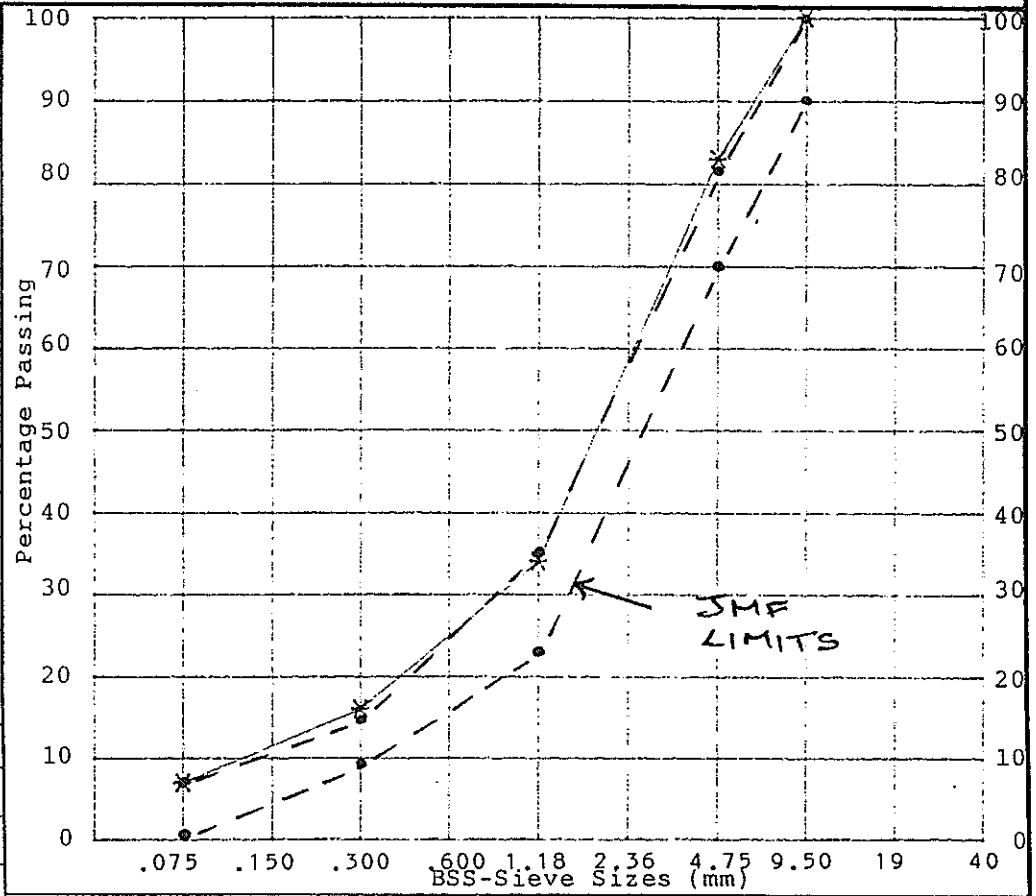
Authorised Signatory:

Client: TRANSIT NEW ZEALAND Contractor: BITUMIX LTD

Job Location: SH 22/GLENBROOK INTERSECTION Date Sample Laid: 2/2/94

File No: 5/2 SAMPLE IN ACCORDANCE WITH ASTM D979-89 Sample Description: MIX 2/3 SLAG

Client Reference		-
Laboratory Reference		3H/94
Laboratory Sample No		3
Mix Temperature on Site (°C)		-
Sieve Size (BSS)	Job Mix Formula	SIEVE ANALYSIS ASTM C136-84a
		%Passing
40.00mm		
19.00mm		
9.50mm	90 – 100	100
4.75mm	70 – 82	83
2.36mm		
1.18mm	23 – 35	34
600µm		
300µm	9 – 15	16
150µm		
75µm	1 – 7	7
Graph Symbols		
BITUMEN CONTENT (±0.2%) In Accordance with Test Method ADL 4.02/15a		5.1%



Tested by: A.A. BROWNE Date: 8/2/94

Checked by: L.J. MURRAY Date: 17/2/94

WORKS Consultancy Services

Auckland Engineering Laboratory
Fanshawe St P.O. Box 5848 Auckland
Ph: 309-6863 Fax: 303-4470

ASPHALTIC CONCRETE RESULT SHEET

Authorised Signatory:

Client: TRANSIT NEW ZEALAND

Contractor: BITUMIX LTD

Job Location: SH 22/GLENBROOK INTERSECTION

Date Sample Laid: 1/2/94

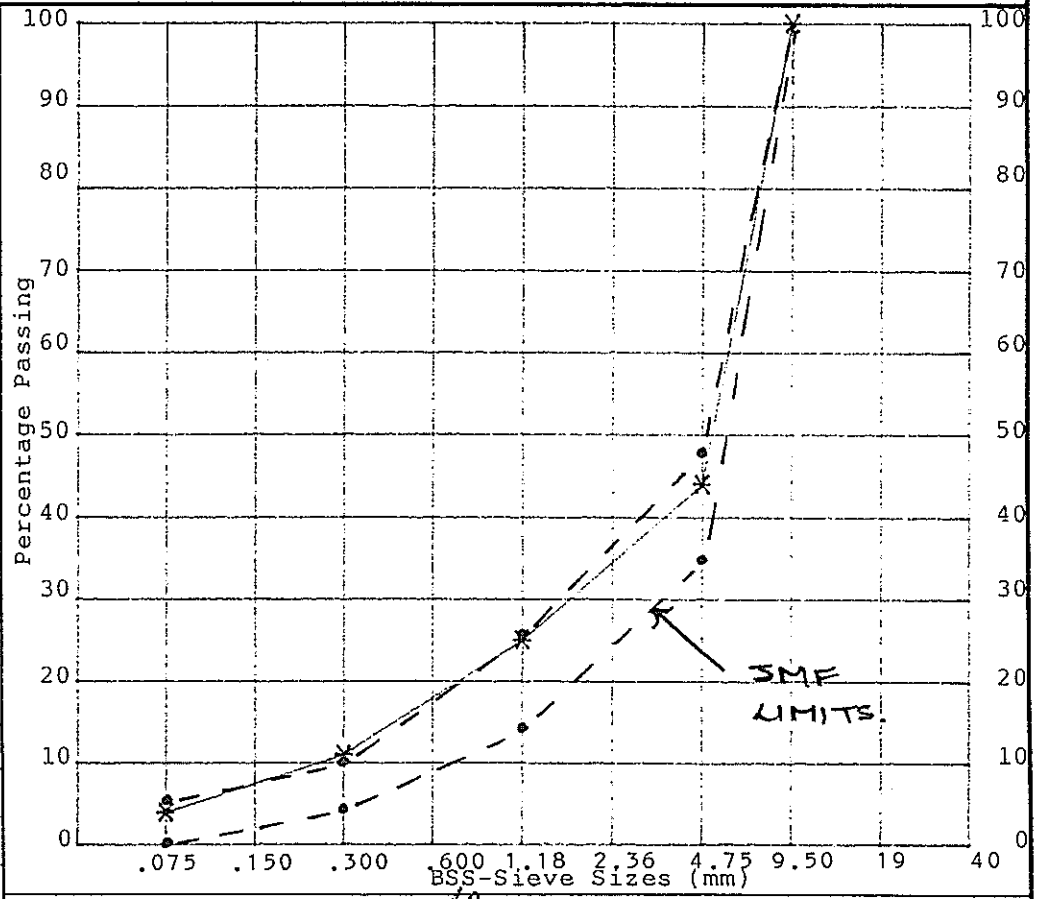
File No: 5/2

SAMPLE IN ACCORDANCE WITH ASTM D979-89

Sample Description: MIX 2 BASALT

Client Reference	–	
Laboratory Reference	3H/94	
Laboratory Sample No	1	
Mix Temperature on Site (°C)	–	

Sieve Size (BSS)	Job Mix Formula	SIEVE ANALYSIS ASTM C136-84a %Passing
40.00mm		
19.00mm		
9.50mm	100	100
4.75mm	36 – 48	44
2.36mm		
1.18mm	14 – 26	25
600µm		
300µm	4 – 10	11
150µm		
75µm	0 – 5	4
Graph Symbols		
BITUMEN CONTENT (±0.2%) In Accordance with Test Method ADL 4.02/15a		3.9%



Tested by: A.A.BROWNE Date: 7/2/94

Checked by: L.J.MURRAY Date: 17/2/94

WORKS Consultancy Services

Auckland Engineering Laboratory
Cnr Fanshawe St & Daldy St, Auckland.
P O Box 5848, Wellesley St, Auckland 1
Phone (09)-309 6863, Fax (09)-303 4470

BITUMEN EMULSION

SAMPLE DESCRIPTION: CM 60/100

FILE NO: 5/2

SOURCE OF SAMPLE: Bitumix Ltd

LAB REF: 1E/94

LOCATION: SH 22/Glenbrook Intersection

CLIENT REF: PR3-0112

SUPPLIED BY: Bitumix Ltd

TEST TITLE	TEST REFERENCE	RESULTS	SPECIFICATION
Particle Charge	BS434:Part 1:1984 Appendix C	Positive	Positive
Residue on 710 micron sieve (to 0.01%)	BS434:Part 1:1984 Appendix D1	0%	0.05% by Mass Maximum
Residue on 150 micron sieve (to 0.01g)	BS434:Part 1:1984 Appendix D2	- g	- g
Stability to Mixing	BS434:Part 1:1984 Appendix E	- %	- %
Water & Binder Content	BS434:Part 1:1984 Appendix F	(B.C.) 63.0%	(B.C.) 60% by Mass Minimum
Viscosity at 20°C (Engler)	BS434:Part 1:1984 Appendix G1	- °E	- °E
Coagulation at Low Temperature	BS434:Part 1:1984 Appendix H	-	-
Storage Stability (Short Test)	BS434:Part 1:1984 Appendix J1	-	-
Storage Stability (Long Test)	BS434:Part 1:1984 Appendix J2	-	-
Viscosity at 25°C (Brookfield)	ASTM D2196:86 TNZ M/1:89-Section 2.2	66.4 cP	40 - 150 cP
Viscosity at 70°C (Brookfield)	ASTM D2196:86 TNZ M/1:89-Section 2.2	High Shear - cP Low Shear - cP	- cP - cP

REMARKS:

TESTED BY: A.A.Browne DATE: 16/2/94

CHECKED BY: L.J.Murray DATE: 21/2/94

APPROVED SIGNATORY:

WORKS Consultancy Services

Auckland Engineering Laboratory
Fanshawe St P.O. Box 5848 Auckland
Ph: 309-6863 Fax: 303-4470

ASPHALTIC CONCRETE RESULT SHEET

Authorised Signatory:

Client: TRANSIT NEW ZEALAND

Contractor: BITUMIX LTD

Job Location: SH22/GLENBROOK INTERSECTION : SITE 36 LWT

Date Sample Laid: 1/2/94

File No: 5/2

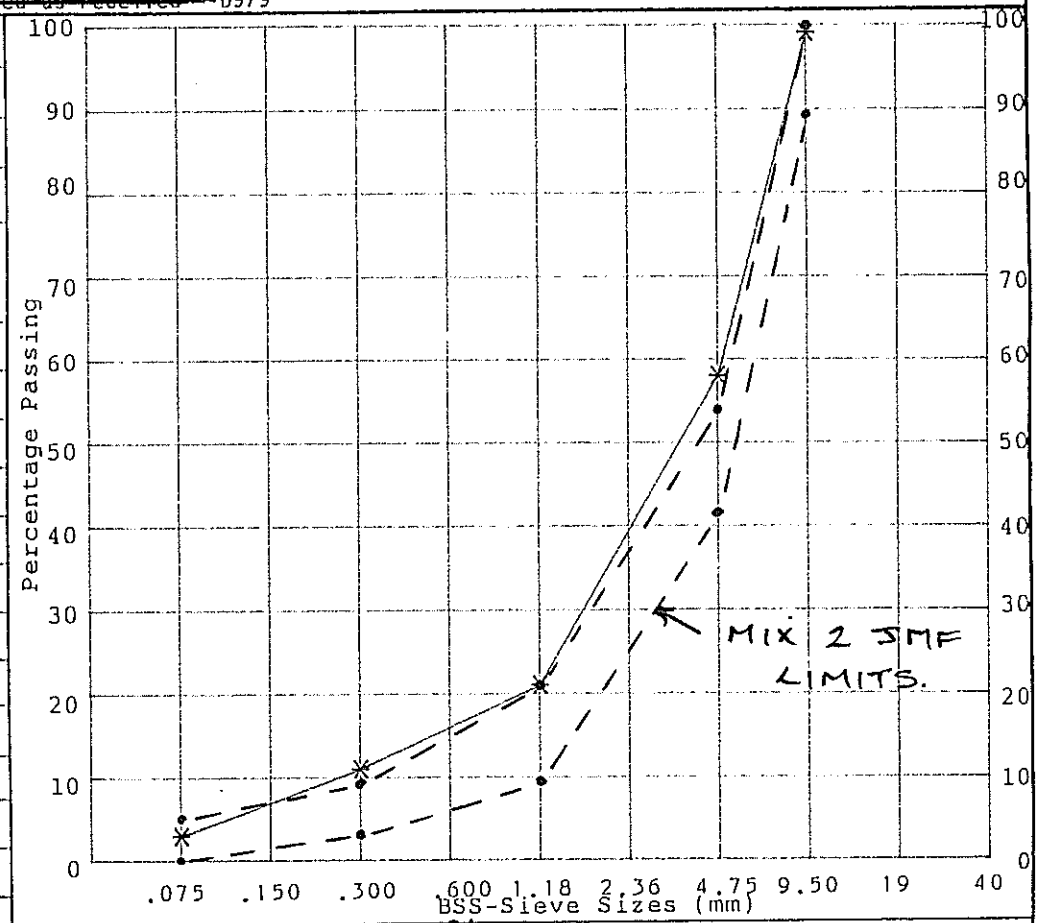
SAMPLING / TESTING DELETE (1 or 2)

(1) Sampled in accordance with ASTM D979

(2) ~~Sample tested as received~~

Sample Description: MIX 2 SLAG

Client Reference		–	
Laboratory Reference		6H/97	
Laboratory Sample No		2	
Mix Temperature on Site (°C)		–	
Sieve Size	Job Mix Formula	SIEVE ANALYSIS ASTM C136-84a	
(BSS)		%Passing	
40.00mm			
19.00mm			
9.50mm	89 – 100	99	
4.75mm	42 – 54	58	
2.36mm			
1.18mm	9 – 21	21	
600µm			
300µm	3 – 9	11	
150µm			
75µm	0 – 5	3	
Graph Symbols			
BITUMEN CONTENT (±0.2%) In Accordance with Test Method ADL 4.02/15a		–%	



Tested by: L.J.MURRAY Date: 22/4/97

Checked by: C.HARRISON Date: 23/4/97

WORKS Consultancy Services

Auckland Engineering Laboratory
Fanshawe St P.O. Box 5848 Auckland
Ph: 309-6863 Fax: 303-4470

ASPHALTIC CONCRETE RESULT SHEET

Authorised Signatory:

Client: TRANSIT NEW ZEALAND

Contractor: BITUMIX LTD

Job Location: SH22/GLENBROOK INTERSECTION : SITE 29 LWT

Date Sample Laid: 2/2/94

File No: 5/2

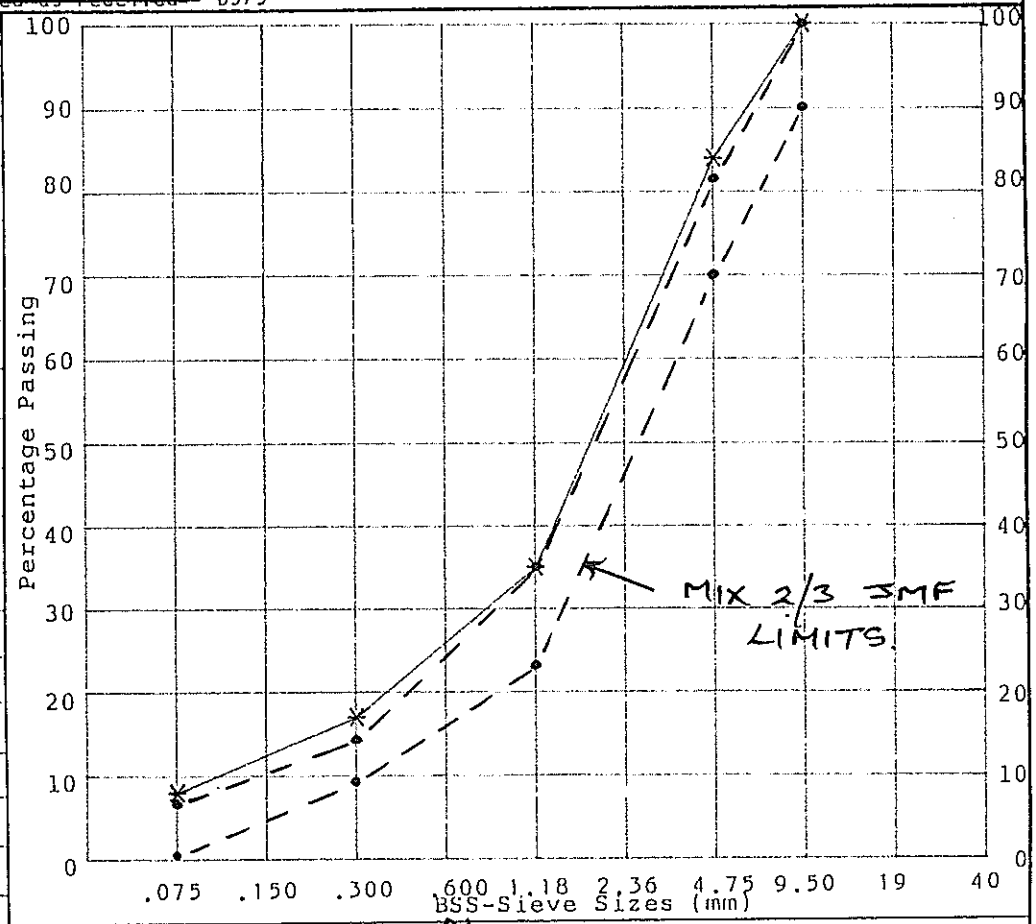
SAMPLING / TESTING DELETE (1 or 2)

(1) Sampled in accordance with ASTM D979

(2) ~~Sample tested as received~~

Sample Description: MIX 2/3 SLAG

Client Reference		–	
Laboratory Reference		6H/97	
Laboratory Sample No		1	
Mix Temperature on Site (°C)		–	
Sieve Size (BSS)	Job Mix Formula	SIEVE ANALYSIS ASTM C136-84a	
		%Passing	
40.00mm			
19.00mm			
9.50mm	90 – 100	100	
4.75mm	70 – 82	84	
2.36mm			
1.18mm	23 – 35	35	
600µm			
300µm	9 – 15	17	
150µm			
75µm	1 – 7	8	
Graph Symbols			
BITUMEN CONTENT (±0.2%) In Accordance with Test Method ADL 4.02/15a		–%	



Tested by: L.J.MURRAY Date: 22/4/97

Checked by: C.HARRISON Date: 23/4/97

APPENDIX 4
SKID RESISTANCE (BPN) RESULTS

OGEM TRIALS SKID RESISTANCE: SHEET 1

TEST POSITION	WHEEL TRACK	SKID RESISTANCE (BPN)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
1	L	69	69	63	69	Mix 2
1	R	66	68	62	68	(Slag)
2	L	65		59	64	
2	R	65		66	69	
3	L	64	69	62	59	
3	R	66	67	62	65	
4	L	70	72	61	62	
4	R	70	69	62	63	
5	L	63		58	59	
5	R	72		60	63	
6	L	63		59	60	
6	R	67		60	60	
7	L	61	70	59	59	
7	R	72	68	63	62	
8	L	69	66	63	63	
8	R	60	71	59	59	
9	L	64		58	58	
9	R	70		61	65	
10	L	66		59	59	
10	R	66		54	57	
12	L	68		59	60	
12	R	69		63	61	
13	L	69	66	64	60	
13	R	70	68	64	59	
14	L	65		63	58	
14	R	60		64	60	
15	L	60	67	64	58	
15	R	60	65	64	58	
17	L	63	64	65	64	
17	R	62	67	66	58	
18	L	60		67	58	
18	R	60		63	57	
19	L	61	69	65	60	
19	R	64	73	62	62	
20	L	67		66	67	
20	R	64		61	60	
21	L	67	72	66	69	
21	R	63	72	63	65	
22	L	67		65	71	

OGEM TRIALS SKID RESISTANCE: Sheet 1 (continued)						
TEST POSITION	WHEEL TRACK	SKID RESISTANCE (BPN)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
22	R	73		69	76	
23	L	76	83	69	61	
23	R	84	80	65	73	
24	L	73		62	62	
24	R	75		67	67	
25	L	72	73	59	70	
25	R	72	79	66	58	
35	L	71	77	61	60	
35	R	69	75	61	60	
36	L	69		62	62	
36	R	64		66	61	

OGEM TRIALS SKID RESISTANCE: SHEET 2

TEST POSITION	WHEEL TRACK	SKID RESISTANCE (BPN)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
11	L	60	67	62	64	Mix 2/3
11	R	66	70	62	63	(Slag)
16	L	64		58	56	
16	R	60		63	57	
26	L	62		58	54	
26	R	58		57	55	
27	L	60	66	55	57	
27	R	58	71	59	58	
28	L	67		61	62	
28	R	64		62	69	
29	L	68	71	56	60	
29	R	65	72	65	63	
30	L	67		66	62	
30	R	67		63	60	

OGEM TRIALS SKID RESISTANCE: SHEET 3

TEST POSITION	WHEEL TRACK	SKID RESISTANCE (BPN)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
31	L	67	67	41	47	Mix 2
31	R	68	67	42	40	Basalt
32	L	68		46	51	
32	R	69		44	50	
33	L	62	70	52	49	
33	R	67	71	54	50	
34	L	66		52	50	
34	R	65		53	51	

APPENDIX 5
TEXTURE SAND CIRCLE RESULTS

OGEM TRIALS TEXTURE SAND CIRCLES: SHEET 1

TEST POSITION	WHEEL TRACK	SAND CIRCLE (mm)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
1	L	235	255	240	235	Mix 2
1	R	230	250	240	230	(Slag)
2	L	240		250	230	
2	R	255		250	252	
3	L	235	255	230	265	
3	R	220	250	220	225	
4	L	245	245	240	265	
4	R	265	250	255	250	
5	L	230		240	260	
5	R	215		235	215	
6	L	270		270	275	
6	R	255		250	295	
7	L	260	235	255	250	
7	R	240	230	255	230	
8	L	250	240	265	265	
8	R	250	245	245	270	
9	L	260		245	270	
9	R	250		225	230	
10	L	240		240	260	
10	R	240		225	260	
12	L	285		235	235	
12	R	225		235	235	
13	L	235	255	235	245	
13	R	235	250	245	235	
14	L	240		255	255	
14	R	260		270	245	
15	L	260	230	270	250	
15	R	240	255	255	260	
17	L	290	240	250	255	
17	R	245	255	250	260	
18	L	240		265	250	
18	R	250		255	250	
19	L	245	255	270	265	
19	R	275	260	250	265	
20	L	250		230	230	
20	R	225		255	255	
21	L	255	250	230	205	
21	R	255	255	265	235	
22	L	270		235	235	
22	R	280		245	300	

OGEM TRIALS TEXTURE SAND CIRCLES: Sheet 1 (continued)						
TEST POSITION	WHEEL TRACK	SAND CIRCLE (mm)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
23	L	205	195	205	215	Mix 2
23	R	195	235	230	205	(Slag)
24	L	220		225	225	
24	R	250		205	220	
25	L	240	240	220	240	
25	R	245	235	205	230	
35	L	275	255	265	285	
35	R	275	260	270	280	
36	L	230		235	215	
36	R	255		255	240	

OGEM TRIALS TEXTURE SAND CIRCLES: SHEET 2

TEST POSITION	WHEEL TRACK	SAND CIRCLE (mm)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
11	L	245	340	325	340	Mix 2/3
11	R	290	325	305	330	(Slag)
16	L	260		335	340	
16	R	270		350	330	
26	L	245		340	315	
26	R	260		270	250	
27	L	250	335	245	245	
27	R	235	270	235	230	
28	L	265		260	250	
28	R	280		215	230	
29	L	215	330	325	290	
29	R	300	365	365	325	
30	L	305		315	295	
30	R	295		290	310	

OGEM TRIALS TEXTURE SAND CIRCLES: SHEET 3

TEST POSITION	WHEEL TRACK	SAND CIRCLE (mm)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	MARCH 97	
31	L	290	295	340	290	Mix 2
31	R	305	265	290	345	Basalt
32	L	275		355	335	
32	R	290		300	310	
33	L	285	325	315	310	
33	R	295	285	290	290	
34	L	295		315	300	
34	R	290		285	305	

APPENDIX 6
DENSITY RESULTS

OGEM TRIALS DENSITY RESULTS: SHEET 1

TEST POSITION	WHEEL TRACK	DENSITY (Kilograms / m^3)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	APRIL 97	
1	L	2121	2245	2272	2292	Mix 2
1	R	2195	1997	2194	2261	(Slag)
2	L	2216		2237	2248	
2	R	2259		2184	2256	
3	L	2242	2128	2157	2155	
3	R	2085	2225	2094	2158	
4	L	2291	2228	2168	2690	
4	R	2323	2265	2238	2341	
5	L	2163		2132	2280	
5	R	2104		2136	2132	
6	L	2273		2253	2362	
6	R	2251		2260	2335	
7	L	2297	2261	2231	2240	
7	R	2259	2199	2150	2182	
8	L	2365	2341	2378	2303	
8	R	2378	2447	2393	2397	
9	L	2297		2212	2403	
9	R	2329		2253	2277	
10	L	2260		2141	2284	
10	R	2368		2155	2328	
12	L	2183		2152	2225	
12	R	2249		2152	2263	
13	L	2219	2190	2207	2259	
13	R	2434	2143	2239	2233	
14	L	2231		2220	2304	
14	R	2311		2307	2370	
15	L	2263	2297	2218	2287	
15	R	2212	2233	2246	2428	
17	L	2233	2281	2263	2315	
17	R	2239	2213	2180	2294	
18	L	2226		2255	2286	
18	R	2209		2222	2192	
19	L	2336	2341	2292	2359	
19	R	2293	2282	2239	2278	
20	L	2150		2170	2280	
20	R	2198		2243	2257	
21	L	2178	2126	2156	2141	
21	R	2301	2190	2271	2196	

OGEM TRIALS DENSITY RESULTS: Sheet 1 (continued)						
TEST POSITION	**WHEEL TRACK**	**DENSITY (Kilograms/m³)**				**MIX TYPE**
		MARCH 94	**MARCH 95**	**MARCH 96**	**APRIL 97**	
22	L	2213		2267	2271	
22	R	2089		2220	2258	
23	L	2001	2220	2126	2124	Mix 2
23	R	2246	2102	2144	2334	(Slag)
24	L	2351		2220	2364	
24	R	2291		2126	2235	
25	L	2289	2297	2214	2270	
25	R	2243	2188	2231	2334	
35	L	2259	2356	2280	2337	
35	R	2325	2369	2265	2361	
36	L	2118		2144	2264	
36	R	2190		2326	2341	

OGEM TRIALS DENSITY RESULTS: SHEET 2

TEST POSITION	WHEEL TRACK	DENSITY (Kilograms / m^3)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	MARCH 97	
11	L	2425	2400	2487	2408	Mix 2/3
11	R	2506	2575	2538	2617	(Slag)
16	L	2455		2297	2648	
16	R	2480		2510	2539	
26	L	2474		2630	2589	
26	R	2309		2409	2475	
27	L	2121	2249	2183	2202	
27	R	2299	2199	2182	2339	
28	L	2484		2245	2368	
28	R	2071		2192	2245	
29	L	2434	2454	2453	2456	
29	R	2380	2440	2418	2474	
30	L	2438		2494	2521	
30	R	2305		2497	2372	

OGEM TRIALS DENSITY RESULTS: SHEET 3

TEST POSITION	WHEEL TRACK	DENSITY (Kilograms / m^3)				MIX TYPE
		MARCH 94	MARCH 95	MARCH 96	MARCH 97	
31	L	2497	2568	2480	2519	Mix 2
31	R	2483	2494	2465	2532	Basalt
32	L	2510		2526	2534	
32	R	2541		2493	2518	
33	L	2436	2666	2528	2525	
33	R	2465	2436	2500	2507	
34	L	2464		2538	2548	
34	R	2426		2442	2519	