WILSON WALTON

BRISBANE CITY COUNCIL

CATHODIC PROTECTION SYSTEM

OPERATIONS MANUAL

LOGAN CITY TRUNK MAIN

WACOL - BRISBANE RIVER

CONTRACT No. R60-92/93

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Approved by: W. A. R. Burns

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1.0 INTRODUCTION

This manual covers the operation of the cathodic protection systems installed for the corrosion protection of the buried steel pipeline that is installed between the Wacol Tie-in and the Brisbane River.

This section of pipeline is part of a multi stage development of a trunk main that tees off from the Mount Crosby to Brisbane pipeline at Anstead and will ultimately terminate at Logan City, south of Brisbane.

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2.0 DESCRIPTION OF STRUCTURE

The pipeline is 2.2 kilometres in length, of 1700mm diameter, of mild steel construction and cement lined internally. The externals of the pipeline are coated with a fusion bonded Polyethylene coating system in order to provide it with primary corrosion protection. The pipeline is a fully welded structure over its entire length. Field welded joints are wrapped in a proprietary commercially available two tape Butyl system. Construction joints and swabbing pits etc. are bridged out with bond cable installations in the pits. Further details are provided on the construction drawings and as per Brisbane City Council standard construction details.

The cathodic protection system comprises of one only 5 Amp 25 Volt DC output capacity impressed current cathodic protection system. This systems provides a complimentary protection system to the coating system in order to prevent corrosion at areas of coating damage (holidays).

In conjunction with the installation of the cathodic protection system, test points have been installed at all air valves, scour valves in the above ground structures.

Grading rings have been installed on the Wacol Section, generally as shown on the construction drawings. The grading rings are connected to the pipeline via polarisation cells. The polarisation cells are housed in field test point boxes as detailed in the construction drawings. A corrosion coupon has been installed at the impressed current installation site adjacent to the pipeline. Permanent zinc monitoring electrodes have been installed at the extremities of the underground section of the pipeline as well as at the transformer rectifier site.

The pipeline between the Wacol Tie-in and the Brisbane River is fitted with a permanent earth that is directly connected to the pipeline via an earth connection box. This earth comprises of zinc coated steel bars and is installed at the chainage nominated in the construction drawings.

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3.0 DESCRIPTION OF SYSTEM

3.1 Impressed Current Cathodic Protection System

The cathodic protection system installed for the protection of the pipeline is of the impressed current type. This system utilises one only transformer rectifier unit to supply direct current to the anodes installed generally as shown on the construction drawings attached.

A cathodic protection unit is housed in a plinth mounted mild steel enclosure and has been installed on Wacol Station Road generally as shown on the construction drawings. The anode groundbed contains 3 only 50mm x 1500 long silicon iron chromium anodes backfilled in metallurgical coke breeze. The anodes are installed to protect the pipeline over its entire buried length. Refer to Locality Plan attached.

The system includes permanent reference electrodes that are buried adjacent to the pipeline at transformer rectifier site. They are also installed at each end of the pipeline. The electrodes are installed to monitor the performance of the cathodic protection system as well as at the transformer rectifier site to enable the unit to be operated in an automatic mode.

Test points are installed along the entire length of the pipeline generally as detailed in the specification and as shown on the construction drawings attached.

A corrosion coupon is installed adjacent to the pipeline at the impressed current cathodic protection installation. At this location the coupon is inter-connected to the system at the transformer rectifier to allow the coupon to be catholically protected in a similar nature to a defect associated with the pipeline coating system.

3. DESCRIPTION CONT'D

Grading rings made from zinc material are buried around all of the structures that terminate at ground level along the length of the pipeline adjacent to the overhead high tension power transmission system. As nominated by Brisbane City Council, the grading rings are connected to the pipeline via the polarisation cells housed in the aboveground installations at each location. They are provided as personnel safety devices for operations personnel in the event of an electrical surge condition on the pipeline.

Insulating flange gasket kits have been installed at each extremity of the pipeline in addition to all air and scour valve installations. At the extremity of the pipeline, an IJP 230 type insulting surge diverter has been installed between the underground section relative to this contract and the pipelines upstream and downstream of this contract.

3.2 Transformer Rectifier Unit

The transformer rectifier unit that has been installed is a 25 volt 15 amp variac controlled unit. The output current is changed linearly in conjunction with the output voltage. The output voltage is controlled by means of a variac variable auto transformer resistor. To increase output voltage and current, the variac is turned to the right. To decrease output voltage and current the variac is turned to the left.

4.0 OPERATION OF SYSTEM

4.1 Impressed Current Cathodic Protection System

The transformer rectifier unit is of the auto transformer operation type and is controlled by a variac variable resistor. This causes a corresponding current to flow between each of the anodes and coating defects on the pipeline.

The output current and operating voltages are monitored from the ammeter and voltmeter installed within the cathodic protection transformer rectifier unit. It should be noted that the output voltmeter will continue to indicate a slight voltage reading even when the Transformer Rectifier unit is switched off. This is because of the potential difference between the structure and the anodes. The voltmeter should only be zeroed when the positive and negative cables are disconnected from the unit.

The Transformer Rectifier unit is supplied and fitted with a four pin plug interrupter socket and associated continuous/bypass mode switch. This allows for externally supplied current interrupters to be fitted during interference testing or instantaneous off potential testing.

Note: **The output of the unit should not be varied without reference to the potential changes produced on the pipeline. Refer below.**

4.2 Monitoring System

The protection potentials of the buried sections of the pipeline are monitored at test points and at each of the locations where the permanent zinc reference electrodes have been installed. The protection potential is a function of the location of the reference electrode, not the point at which electrical contact is made with the structure. Each of the zinc reference cells can be tested in turn by monitoring the DC voltage between each of the permanent reference cell wires and the structure/pipeline connection monitoring wires located in each of the Field Test Point installations or within the Transformer Rectifier enclosure itself.

The value of the ON reference potential at the Transformer Rectifier is set to ensure that the 'instant OFF' potential along the entire pipeline (determined by field tests) is between -0.85 and -1.20 volts (WRT $Cu/CuSO_4$) or + 0.25 and -0.25 volts (WRT Zinc).

The soils on the pipe route vary in nature. They are predominantly black clays and silt with some sandstone/ shale experienced. The positioning of the anode bed is aimed at allowing an even distribution of the cathodic protection current to the pipeline along its route with minimal interference, if any being caused to the foreign structures.

Note: Instant OFF potentials more negative than -1.200 volts (-1200 mV WRT $Cu/CuSO_4$) can cause disbonding for certain types of coatings in normal operating conditions. This is of less significance in this installation as the pipeline's coating resistance to coating disbonding is good.

Precautions should be taken to minimise the overall structure potentials wherever possible. The system should, wherever possible, always be adjusted within the limitation specified.

4.0 OPERATION CONT'D

4.3 Measurement of *ON & INSTANTANEOUS OFF* Potentials

It is well documented and recognised that the "ON" potential readings most often contain a degree of error in the reading due to the current flowing through the soil between the anode bed and the pipeline under protection.

In order to remove this error, (referred to as IR ERROR or IR Component) it is normal practice to switch the cathodic protection system/s off. At the instant that the cathodic protection system/s are switched off, one records the "INSTANT OFF" polarised potential of the structure.

If the technologist conducting the testing does not have access to a data logging type instrument, it is normal practice to record the "INSTANT OFF" potential within one second of the system/s switching off.

It needs to be understood that the potentials that are relevant when conducting a survey of the pipeline are the maximum "ON " potential and the "INSTANT OFF" potential voltage. The OFF readings will continue to decay once the system is deactivated. Readings many seconds or more after the rectifiers are switched off are of little value as any record of corrosion protection of the pipeline. The zinc grading rings were not directly connected to the pipeline during the commissioning stage as a consequence of the polarisation cell installations.

4.0 OPERATION CONT'D

4.4 Digital Synchronous Interrupters

For normal testing of the Wacol to Brisbane River section of pipeline only, it is possible to use one single current interrupter. However should it be necessary to switch a number of systems along the Logan City Main, to conduct instant off potentials or interference testing, it will be necessary to use synchronously switched interrupters. Such units would be MC Miller Type JR1 or JR1Y units. A copy of the data sheet on these units is attached.

Under normal operating conditions the TEST/NORMAL switch on the transformer rectifier unit should be in the "Normal" or "Continuous" mode.

If the interrupter is to be utilised, the four pin plug and leads etc. should be connected prior to switching the unit to the "Test" or Continuous setting mode.

5.0 MAINTENANCE

The cathodic protection system should be reliable in operation and require only minimal maintenance. However, we would recommend the following preventative maintenance program to ensure the satisfactory operation of the system.

5.1 Monthly Inspection

(a) Check the operation of the transformer rectifier unit and record its output (Amps & Volts DC).

(b) Check and record pipeline potentials against the permanent zinc reference electrode at each of the electrode installation test point facilities.

5.2 Six Monthly Inspection

(a) Carry out a visual inspection of components installed within the system.

(b) Check the condition of the transformer rectifier unit. Remove the output fuse and record the maximum and minimum output voltage to check operation of the control circuit. Recalibrate to zero volts, replace the output fuse and reactivate the unit/s. If any adjustment of the unit/s is required, refer to the technical operations manual for the transformer rectifier unit/s.

(c) Check pipeline potentials at the test point nearest the rectifier and calibrate the permanent zinc electrodes at the groundbed test point using a portable copper/copper sulphate reference electrode.

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5.0 MAINTENANCE CONT'D

(d) Monitor the potentials of the pipeline using a portable copper/copper sulphate reference electrode and a MC MILLER type LC4 variable input resistance corrosion meter or equivalent. If practical, the electrode should be located centrally over the top of the pipeline. Ideally six monthly inspections should be conducted by an independent corrosion consultant, but on a maximum of 12 monthly intervals.

(e) We suggest that the results of 5.1 and 5.2 above be sent to Wilson Walton International (Qld) Pty Ltd on a monthly basis to permit an appraisal of the system operation and to provide a history of protection maintained on the structures. This will enable recommendations to be made where considered necessary to ensure continued safe operation of the system/s.

6.0 FAULT FINDING

If the system is not operating satisfactorily, reference to the following procedures should assist in locating the fault.

i) No Voltage, No Current

(a) Check the main switch.
(b) Check the AC fuse.
(c) Check the AC power supply to the unit.
(d) Check the current limiting setting on the auto controller.

ii) Voltage, No Current

(a) Check the OC output fuse.
(b) Check connections in the "Groundbed Terminal Box"
(c) Check the rectifier bridge.
(d) Check structure negative connections.
(e) Check OC cabling.

iii) Low Voltage, Low Current

(a) Check the rectifier bridge.
(b) Check the T/R unit output adjustment.
(c) Check the "SET POINT" setting on the automatic controller of the transformer rectifier unit.
(d) Check the potential of the fixed, permanent zinc reference cell that drives the automatic controller in the T/R unit. If considered faulty, replace the permanent cell with a portable cell temporarily to confirm satisfactory operation of the transformer rectifier unit/s. This will also require adjustment of the SET POINT on the control.

iv) Structure Potentials Insufficiently Negative

(a) Check the operation of the cathodic protection system.
(b) Check the adjustment of the transformer rectifier unit.
(c) Check the "SET POINT" of the transformer rectifier unit to confirm that an adequate potential setting has been programmed. Also re-check the current limiting setting on each unit has not been set a too low a threshold setting.

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6. FAULTS CONT'D

v) <u>Structure Potentials Abnormally Negative</u>

(a) Check the operation of the cathodic protection system.
(b) Check the adjustment to transformer rectifier.
(c) Check the effectiveness of insulating flanges.
(d) Check the "SET POINT" of the transformer rectifier unit has not been set too high.

Following location and rectification of the fault, an examination of the system should be carried out to determine the cause and avoid a recurrence of the fault. The cause of the fault and the rectification work carried out should be recorded in the system log book and appear in the monthly operating log.

Any modifications or alterations to the equipment or the system/s should be recorded in a monthly log, and a copy should be forwarded to Wilson Walton International (Qld) P/L in order that an up dated profile can be maintained. This will assist in consultation in times of malfunctioning should WWI be called upon to assist.

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7.0 MAINTENANCE PARTS, SERVICE

Maintenance parts and service for the complete system are available from the nearest office of Wilson Walton International.

Queensland: 30 Chetwynd Street,
Loganholme, Brisbane,
4129.

Ph. 07 - 801 4077
Fax 07 - 801 1044.

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APPENDIX I

Technical Specification

BRISBANE CITY COUNCIL

DEPARTMENT OF WATER SUPPLY AND SEWERAGE

INVITATION TO TENDER

DOCUMENTS FOR

LOGAN CITY TRUNK MAIN AMPLIFICATION

CONSTRUCTION OF MILD STEEL WELDED PIPELINE

ANSTEAD TO BRISBANE RIVER

Sealed Tenders, endorsed : "TENDER FOR CONTRACT NO. - R. 97/92/93"
GENERAL MANAGER
BRISBANE CITY COUNCIL

Tender Documents must be delivered by placing same in the Tender Box on the Customer Service Centre, Ground Floor, Brisbane Administration Centre, 69 Ann Street, Brisbane, not later than 12 Noon on the closing date mentioned below, or by posting same to reach the Town Clerk by this time and date.

Notice advising location of opening of Tenders will be on top of Tender Box, Brisbane Administration Centre.

The charge for each copy of the documents relative to this contract is *$100.00 NON-RETURNABLE*

DATE OF ISSUE : 24 April 1993 **DATE OF CLOSING : 28 May, 1993**

1SCC491a(M6 10/88)

TYPW(C.03/78.1147)

BRISBANE CITY COUNCIL

DEPARTMENT OF WATER SUPPLY AND SEWERAGE

CONTRACT NO. R. 97/92/93

LOGAN CITY TRUNK MAIN AMPLIFICATION CONSTRUCTION OF MILD STEEL WELDED PIPELINE ANSTEAD TO BRISBANE RIVER

PART 7C - SPECIFICATION FOR EARTHING AND CATHODIC PROTECTION SELECTED SUBCONTRACTOR WORK

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TYPW(C.03/01.765)

BRISBANE CITY COUNCIL

DEPARTMENT OF WATER SUPPLY AND SEWERAGE

SPECIFICATION FOR EARTHING AND CATHODIC PROTECTION SELECTED SUBCONTRACT WORKS

7C.1 GENERAL

The Contractor shall subcontract the following works to a Select Subcontractor:

(a) Provision of advice on temporary pipeline earthing and construction safety under high voltage power lines.

(b) Design of the temporary earthing equipment.

(c) Design and installation of the permanent earthing system including calculations, resultant induced voltages under all conditions at various pipe locations, and all documentation.

(d) Design and installation of earth grading rings at valve pits within the influence of the high tension power lines.

(e) Performance of a High Voltage Induction Study of the pipeline route by a suitably qualified and experienced engineer, who is a member of Institution of Engineers, Australia. The completion of this study prior to the commencement of the construction schedule is not essential as the installation of the Earth Grading Rings is intended to proceed.

(f) Design and installation of a suitable impressed current cathodic protection system including calculations and documentation, including provision of suitable power supply, liaison with SEQEB and connection charges.

(g) Co-ordination and liaison with the Queensland Electricity Commission (QEC).

(h) Liaison with foreign structure owners in accordance with the Queensland Electricity Act.

(i) Provision of drawings "For Construction" and "As Built", including all documentation and calculations.

(j) Any other aspect of the works not specifically covered by this Specification but necessary for the satisfactory completion and commissioning of the Earthing and Cathodic Protection works.

Full documentation is required for all stages of the installation, including design, installation and as-built, for both hazardous voltage mitigation and cathodic protection. All documentation shall be submitted to the Superintendent for approval prior to payment.

The Contractor shall be responsible for the suitability of the design, for the suitability of the materials selected and for the installation of both the earthing systems and the cathodic protection system.

7C.2 SELECT SUBCONTRACTORS

The Contractor shall subcontract the select subcontract works to one of the following select subcontractors:

(a)	Corrosion Control Engineering Pty Ltd	(07) 395 6374
(b)	Corrosion Specialists Pty Ltd	(07) 376 4006
(c)	Solomon Corrosion Consulting Services Pty Ltd	(03) 598 8660
(d)	Wilson Walton International Pty Ltd	(07) 343 8633

7C.5.4 Valve Pit Polarising Test Point

All valve pits on this pipeline shall be fitted with earth potential grading rings. The polarising test points shall consist of:

(a) Hot dip galvanised upstand and suitably sized lockable junction box
(b) 35 mm² earth building wire for pipeline and grading ring connections
(c) Grading ring material
(d) Passive voltage surge device

The grading rings shall be located a minimum of 1 m offset from the outside circumference of the valve pit plinths.

Cable entries to valve pits, where required shall be via suitably sized conduits which shall be effectively sealed on completion of the grading ring installation.

Selection of the passive voltage surge device shall meet the following criteria as this pipeline is not regularly inspected. This voltage surge device shall be non consuming and re-usable following a voltage surge with any maintenance requirements being limited to annual inspections.

In addition the voltage surge device shall energise the grading ring when a potential difference of approximately 2 volts is applied between the pipeline and grading ring.

Where test point and grading ring installations coincide then the test point cabling shall be incorporated and external test point monitoring facilities shall be provided.

7C.5.5 Insulating Joint Surge Divertor

Mainline insulating joints shall be fitted with gas charged surge divertors or similar which shall be mounted within a test point junction box.

In cases where polarising earth grading rings are installed the surge divertors should be incorporated. Typically the Critec IJP230 or similar should be considered.

7C.6 CATHODIC PROTECTION SYSTEM

7C.6.1 General

The subcontractor shall be responsible for the design, documentation and installation of a cathodic protection (CP) system. The CP design is to be compatible with the permanent earthing design and grading ring installations where applicable. The cathodic protection system shall be designed to achieve a uniform electrode potential of -0.86 volts to -1.1 volts (instantaneous off) along the entire length of the pipeline with respect to a $Cu/CuSO_4$ reference cell.

(FOR INFORMATION ONLY) The pipeline project is divided into three (3) separate contracts with the Brisbane River crossing contract being electrically isolated and bifurcated. The pipeline river crossing will incorporate a permanent earthing system on each side of the Brisbane River.

7C.6.2 Test points

Above ground test points shall be provided within the design at approximately 0.5 km spacings and shall be located at valve pits or real property boundaries where practicable. Above ground test points shall be comprised of:

(a) mild steel baseplate
(b) mild steel pipe upstand
(c) suitably sized metallic enclosure

7C.6.8 Insulating Flange Joints

(FOR INFORMATION ONLY)
All specified insulating flange joints shall be electrically isolated by non conducting full faced gaskets suitable for the duty required. The Table C flange gaskets shall be the equivalent of Central Plastics G3 Phenolic.

In addition all insulating flange bolts shall be effectively isolated on both sides of the flange by proprietary sleeve and washer kits, preferably of the combined sleeve and washer type. Typically, Central Plastics Minlon or high density polyethylene sleeves shall be acceptable.

7C.6.9 Testing

All insulation joints shall be tested after installation to ensure adequate insulation. Testing shall be carried out in three stages, prior to backfilling, after backfilling and after the main is charged with water. The overall integrity of the pipeline insulation shall be tested after backfilling has been complete. Any holidays or defects shall be rectified. The cost of all testing and rectification shall be deemed to be included in the Contract Sum.

7C.6.10 Rectifier Unit

The Rectifier Unit shall be installed in Cubicle (Plinth Mounted) suitable for roadside location. Cubicle to include SEQEB metering and all compartments to be lockable with Lockwood 201 series locks.

The rectifier is to include standard 4 pin interrupter socket for instantaneous "Off" potential measurements, and shall include voltage and current indicators.

Telemetry Requirements

The cabinet shall provide sufficient space to allow installation of data logging and telemetry equipment by others. Minimum space on escutcheon 300 x 400 - 200 deep.

A terminal strip shall be provided for wiring into data logging by others. Data logger inputs/outputs are as follows: (To be wired to terminal strip)

1. Rectifier current
2. Rectifier voltage
3. De energise rectifier for remote installations off potential measurements
4. Local pipe reference potential
5. Soil resistivity at rectifier location

Data Logger System Voltage - analog $\pm$ 2.5 V dc or 4 -20mA
- Digital + 32 V dc

Rectifier unit circuitry shall be suitable for remote de-energisation of rectifier unit.

The Contractor may propose an alternative subcontractor, for approval by the Superintendent, to carry out the select subcontract works.

7C.3 MATERIALS

All materials utilised for temporary or incorporated into permanent works shall be new and suitable for the service required.

7C.4 RELEVANT STANDARDS AND CODES

All select subcontract work shall comply to the relevant Australian Standards detailed below, where applicable, or where no such standards exist then relevant British or NACE standards should be considered.

AS 1020 The control of undesirable static electricity.
AS 2239 Galvanic (sacrificial) anodes for cathodic protection.
AS 2832 Guide to the cathodic protection of metals Parts 1 and 2.
AS 3000 Wiring rules.
AS 1768 Lightning protection.
AS 2210 Safety footwear.
Queensland Electricity Act Part 10.
Queensland Electricity Regulations Part 8 1989.

7C.5 EARTHING

7C.5.1 General

The proposed pipeline closely parallels QEC easements where additional safety requirements and procedures are necessary due to the proximity of high voltage power lines sub station, where hazardous induced voltages and fault currents may develop.

The subcontractor shall review the existing safety specification for personnel and equipment in order to assist the Contractor.

7C.5.2 Temporary Pipeline Earthing

Temporary pipeline earthing shall be designed for installation by the Contractor at distances not exceeding 0.5 km. The ends of each section of pipeline where work is being undertaken shall also be earthed.

All temporary pipeline earthing shall not exceed a maximum of 15 ohms earth stake to soil resistance as per the standard structure to remote earth test procedures.

7C.5.3 Permanent Pipeline Earthing

The pipeline shall be connected to at least two (2) earth beds by the subcontractor as required by the design calculations in respect of hazardous voltages.

The permanent earth bed shall be comprised of zinc anode material, or an alternative material approved by the Superintendent and shall not exceed a maximum of 2 ohms resistance, earth bed to remote earth as per the standard structure to remote earth test procedures.

Scour valve outlets shall be electrically isolated from the mainline and shall be fitted with a trailing earth strap for discharge of static electrical charges.

All mild steel components shall be hot dip galvanised for corrosion resistance.

Test points shall be installed during construction such that they may be utilised for earthing and/or cathodic protection.

Where test point and grading ring installations coincide then the test point cabling shall be incorporated and external test point monitoring facilities shall be provided. External connections and permanent identification shall be provided for all reference and other connections at test points.

7C.6.3 Cabling

Test point cabling shall comprise one 6 mm² single and at least one 16 mm² core double insulated (SDI) (black sheath) with a minimum of two (2) pipe connections being made at field joints.

Sacrificial anode cabling shall be comprised of 6 mm² SDI (red sheath), if installed.

Impressed current systems shall be comprised of:

(a) DC positive and anode cabling shall be a minimum of 16 mm² SDI (red sheath).

(b) DC negative cabling shall be a minimum of 16 mm² SDI (black sheath) with two (2) pipeline negative connections being provided.

Zinc reference electrode cabling shall be a minimum of 4 mm² building wire (yellow sheath) where installed.

Polarisation coupon cabling shall be installed at the impressed current drain point test point. Comprised on two (2) 2.5 mm² building wires, as a minimum, sheathed red and black or similar.

Earthing and Grading Ring cabling shall be 35 mm² earth building cable.

7C.6.4 Polarisation Coupon(s)

Polarisation coupons shall be comprised of a mild steel disc with a minimum cross sectional area of 25 mm dia. Two (2) colour coded 2.5 mm² building wires shall be attached and encapsulated prior to burial at the pipe invert depth adjacent to the drain point test points. Additional coupons may be installed in areas where high soil resistivity is encountered.

7C.6.5 Zinc Reference Electrodes

Stabilised zinc reference electrodes shall be installed adjacent to each polarisation coupon. The zinc reference electrodes shall be of minimum dimensions 20 mm dia x 250 mm long and be prepackaged in a gypsum bentonite backfill. These electrodes shall be pre-wetted prior to installation.

7C.6.6 Sacrificial Anode Current Shunts

Where sacrificial anodes are installed for cathodic protection purposes a calibrated current shunt of 0.1 ohm resistance shall be incorporated into each anode test point. Sacrificial anodes shall have a full operational life in excess of 10 years.

7C.6.7 Impressed Current Groundbeds

The design of impressed current groundbeds shall conform to the Queensland Electricity Act and Regulations with regard to the level of interference to foreign structures. Ground beds shall be located, where possible, in Council or public access areas. Impressed current anodes shall have a full operational life in excess of 15 years.

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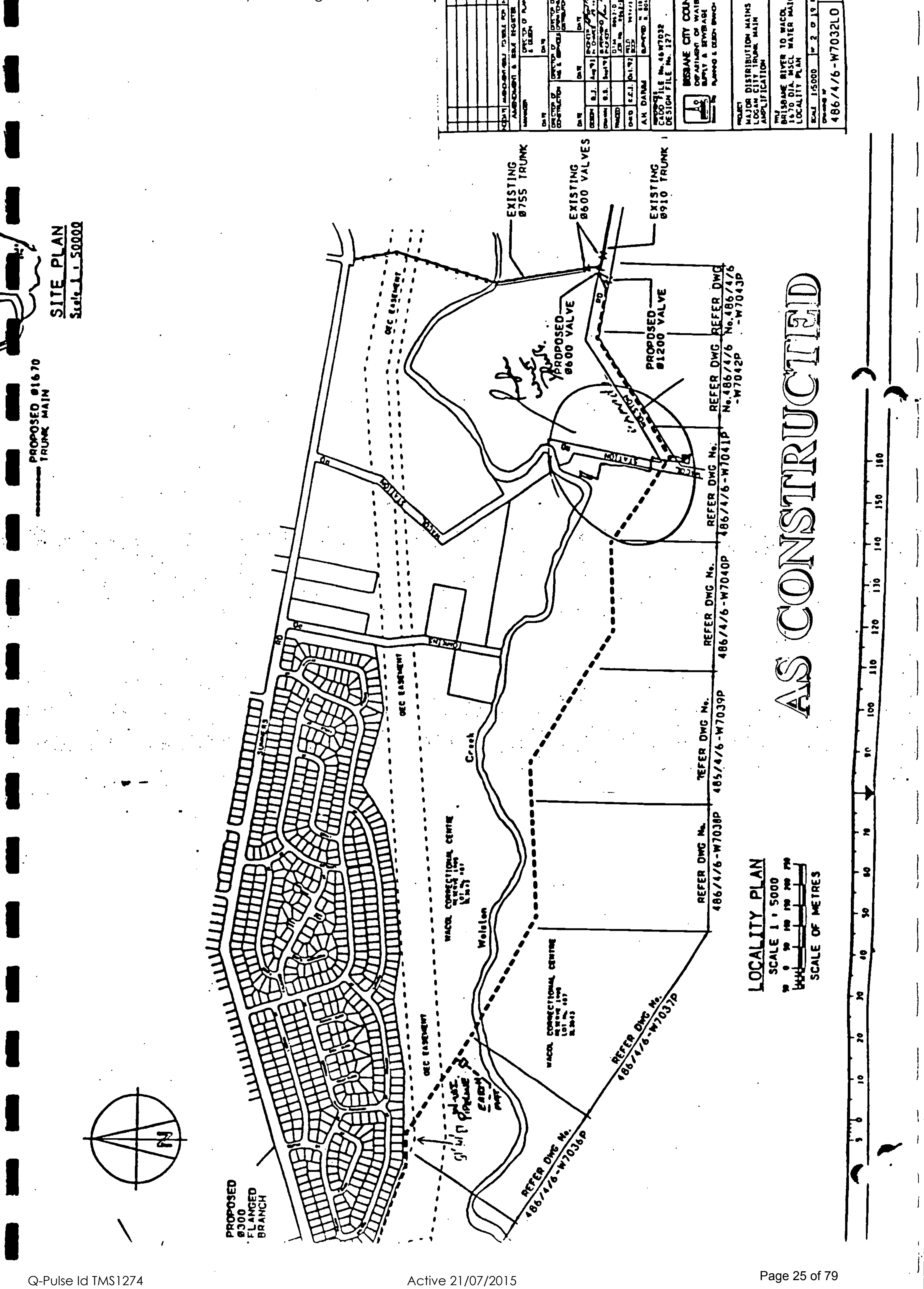
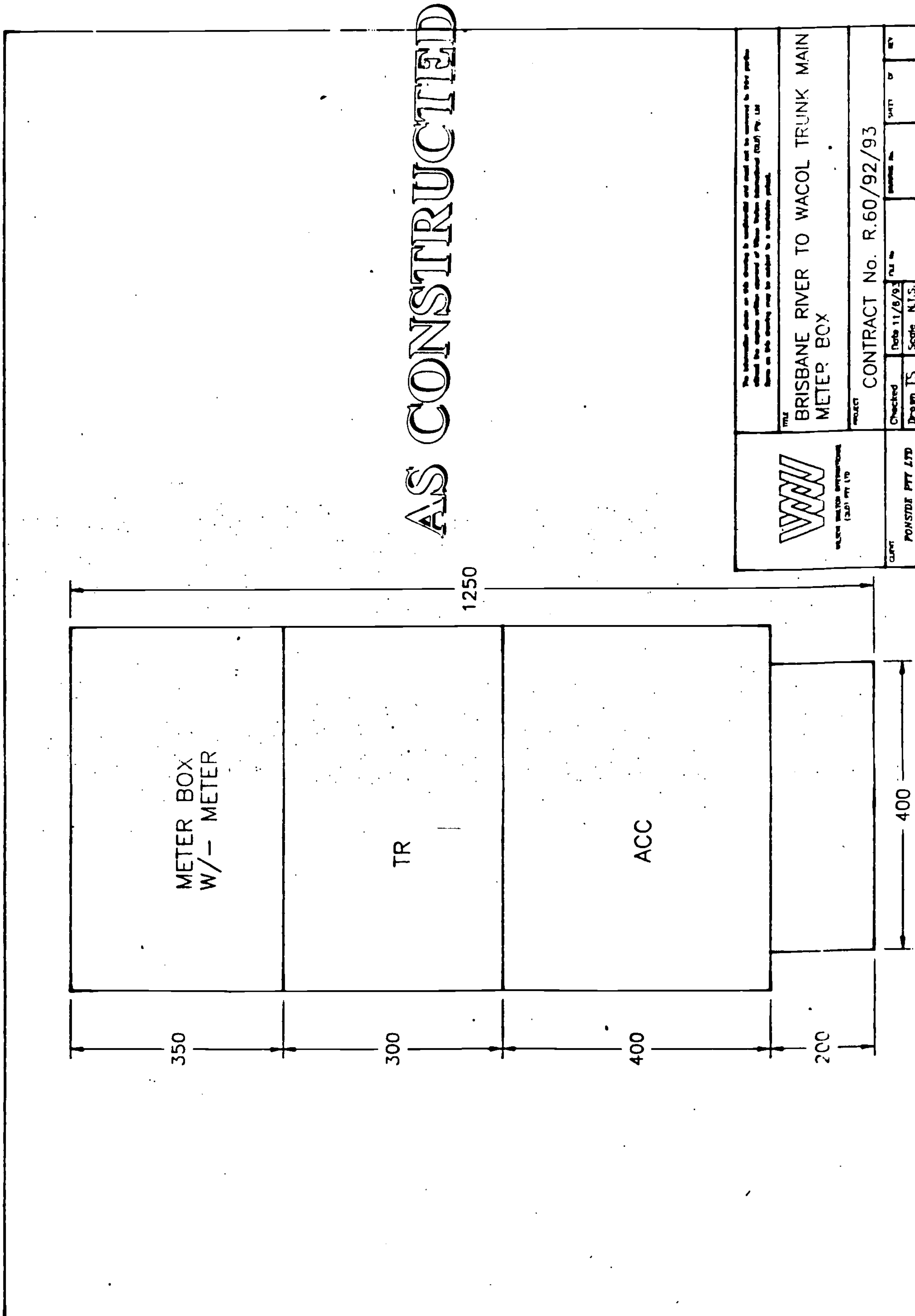
APPENDIX II

Transformer Rectifier Data Sheets & Drawings


SITE PLAN
Scale 1 : 50000
PROPOSED Ø1670 TRUNK MAIN
EXISTING Ø755 TRUNK
EXISTING Ø600 VALVES
EXISTING Ø910 TRUNK
PROPOSED Ø600 VALVE
PROPOSED Ø1200 VALVE
REFER DWG No.486/4/6-W7043P
REFER DWG No.486/4/6-W7042P
REFER DWG No. 486/4/6-W7041P
REFER DWG No. 486/4/6-W7040P
REFER DWG No. 485/4/6-W7039P
REFER DWG No. 486/4/6-W7038P
REFER DWG No. 486/4/6-W7037P
REFER DWG No. 486/4/6-W7036P
PROPOSED Ø300 FLANGED BRANCH
OEC EASEMENT
Wolston Creek
WACOL CORRECTIONAL CENTRE
AS CONSTRUCTED
LOCALITY PLAN
SCALE 1 : 5000
SCALE OF METRES
BRISBANE CITY COUNCIL
MAJOR DISTRIBUTION MAINS LOGAN CITY TRUNK MAIN AMPLIFICATION
BRISBANE RIVER TO WACOL 1670 DIA. MSCL WATER MAIN LOCALITY PLAN
486/4/6-W7032L0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300
400
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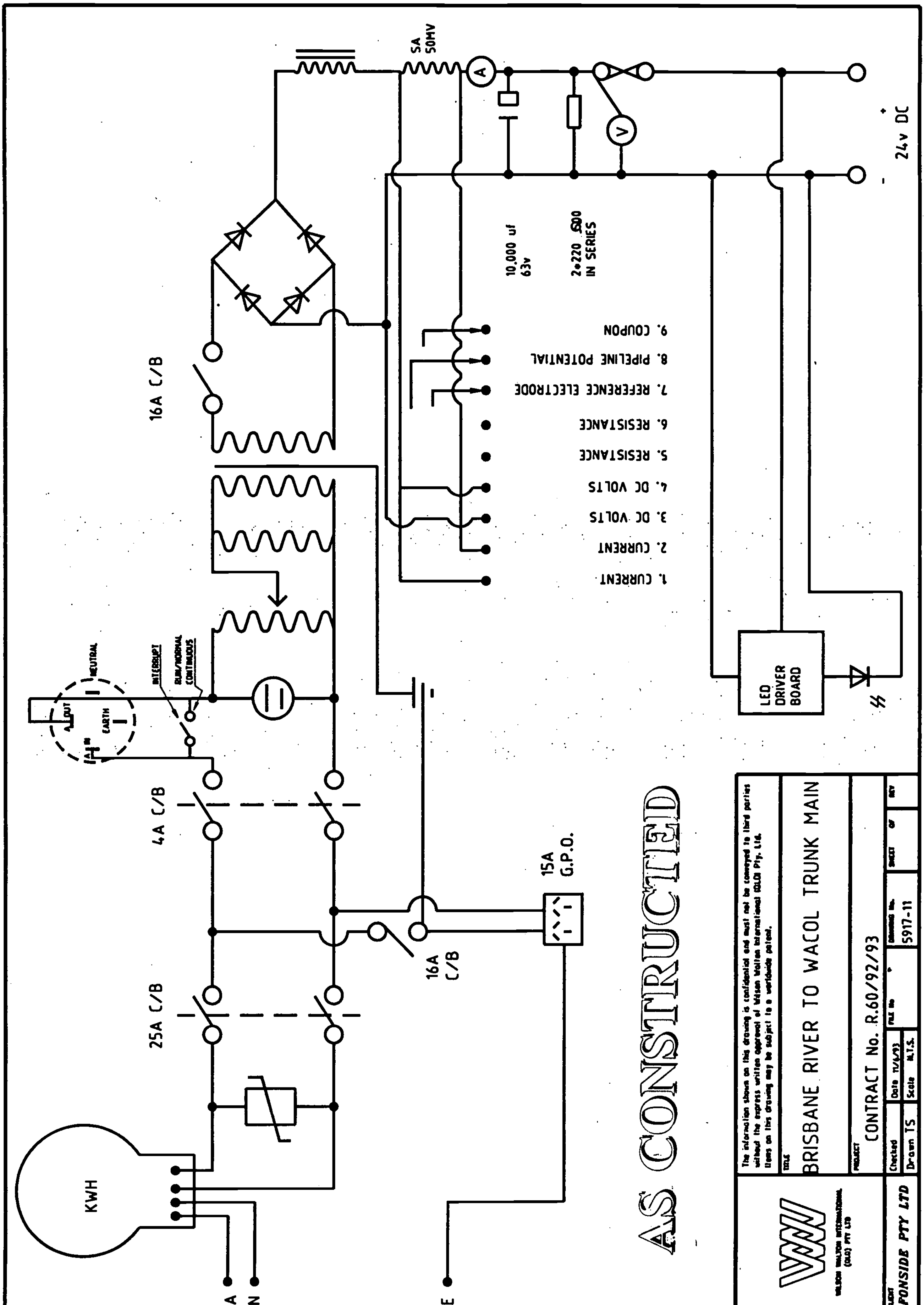
SA
50MV
24v DC
10,000 uf
63v
IN SERIES
9. COUPON
8. PIPELINE POTENTIAL
7. REFERENCE ELECTRODE
6. RESISTANCE
5. RESISTANCE
4. DC VOLTS
3. DC VOLTS
2. CURRENT
1. CURRENT
16A C/B
4A C/B
25A C/B
16A
C/B
15A
G.P.O.
NEUTRAL
EARTH
INTERRUPT
RUN/NORMAL
CONTINUOUS
KWH
LED
DRIVER
BOARD
A
N
E
AS CONSTRUCTED
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CONTRACT No. R.60/92/93
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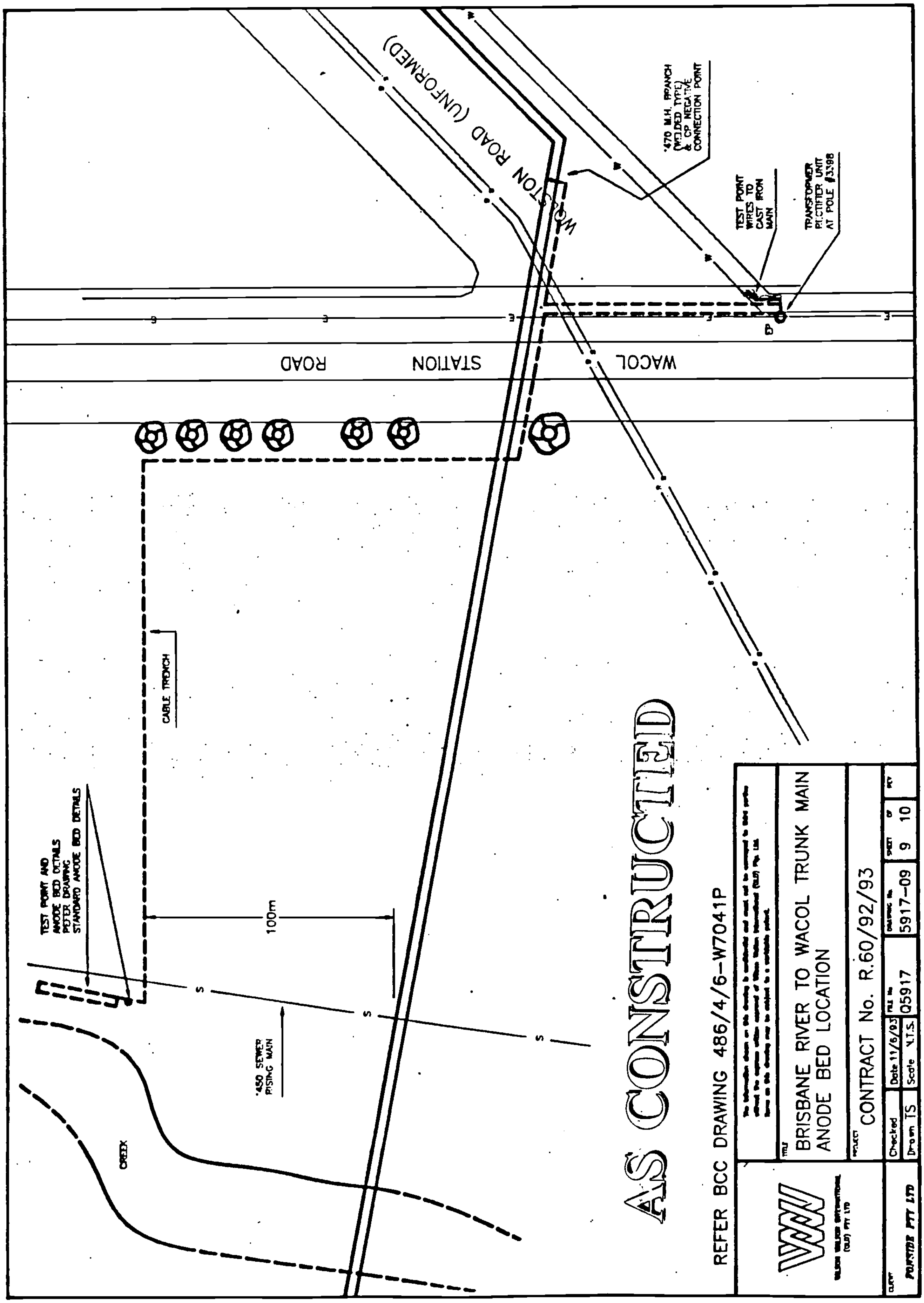
Drawn TS
PONSIDE PTY LTD



AS CONSTRUCTED
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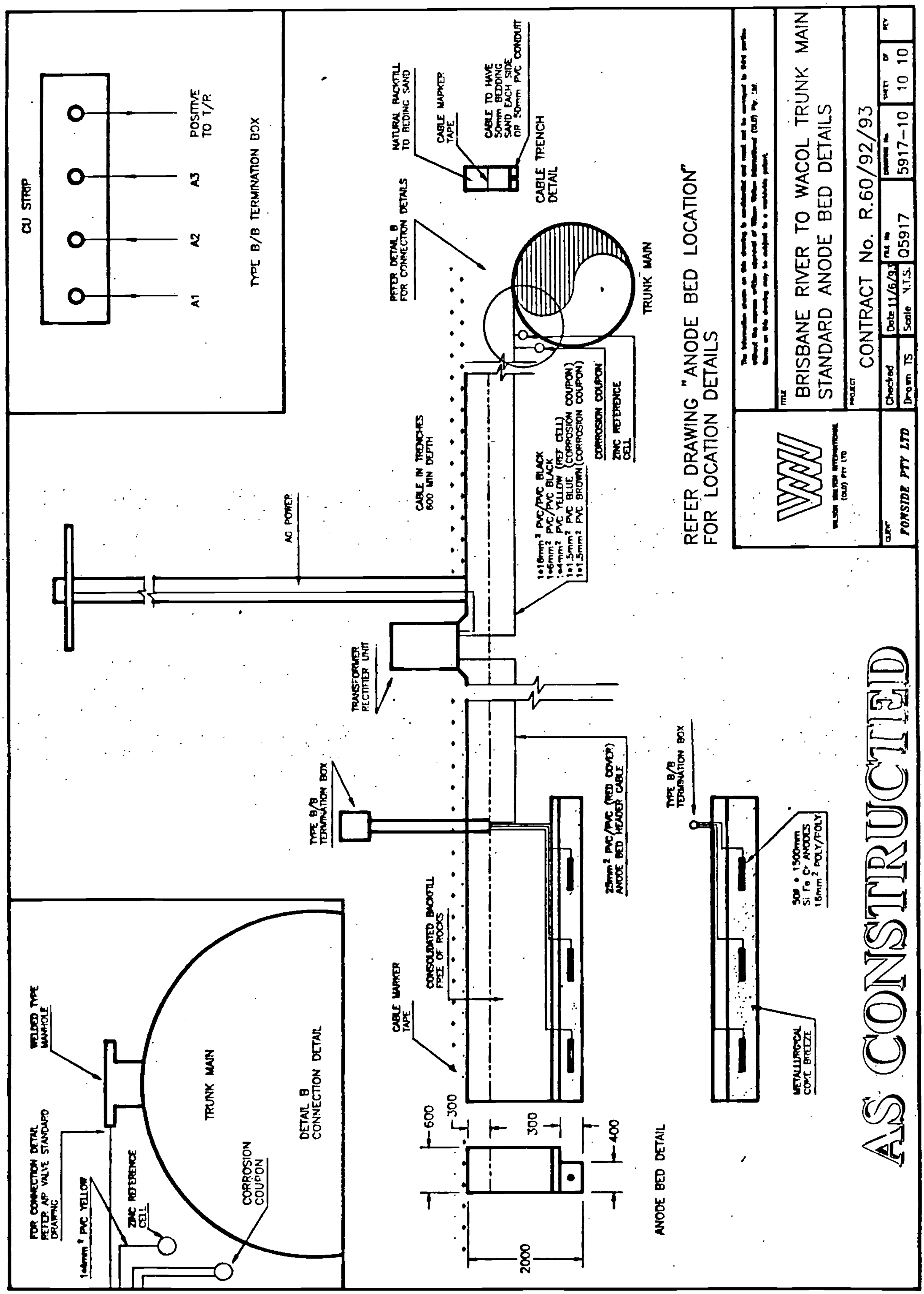
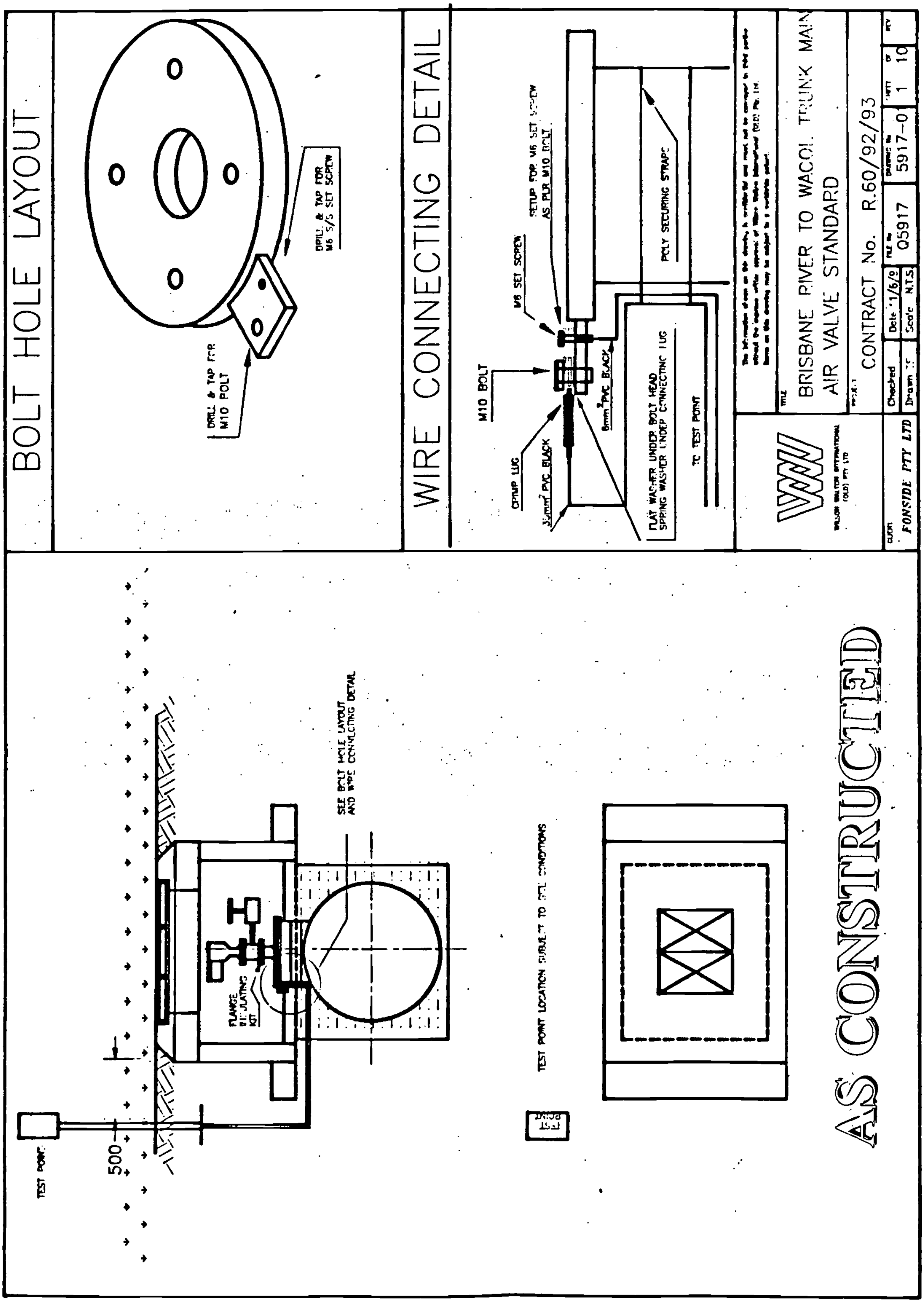
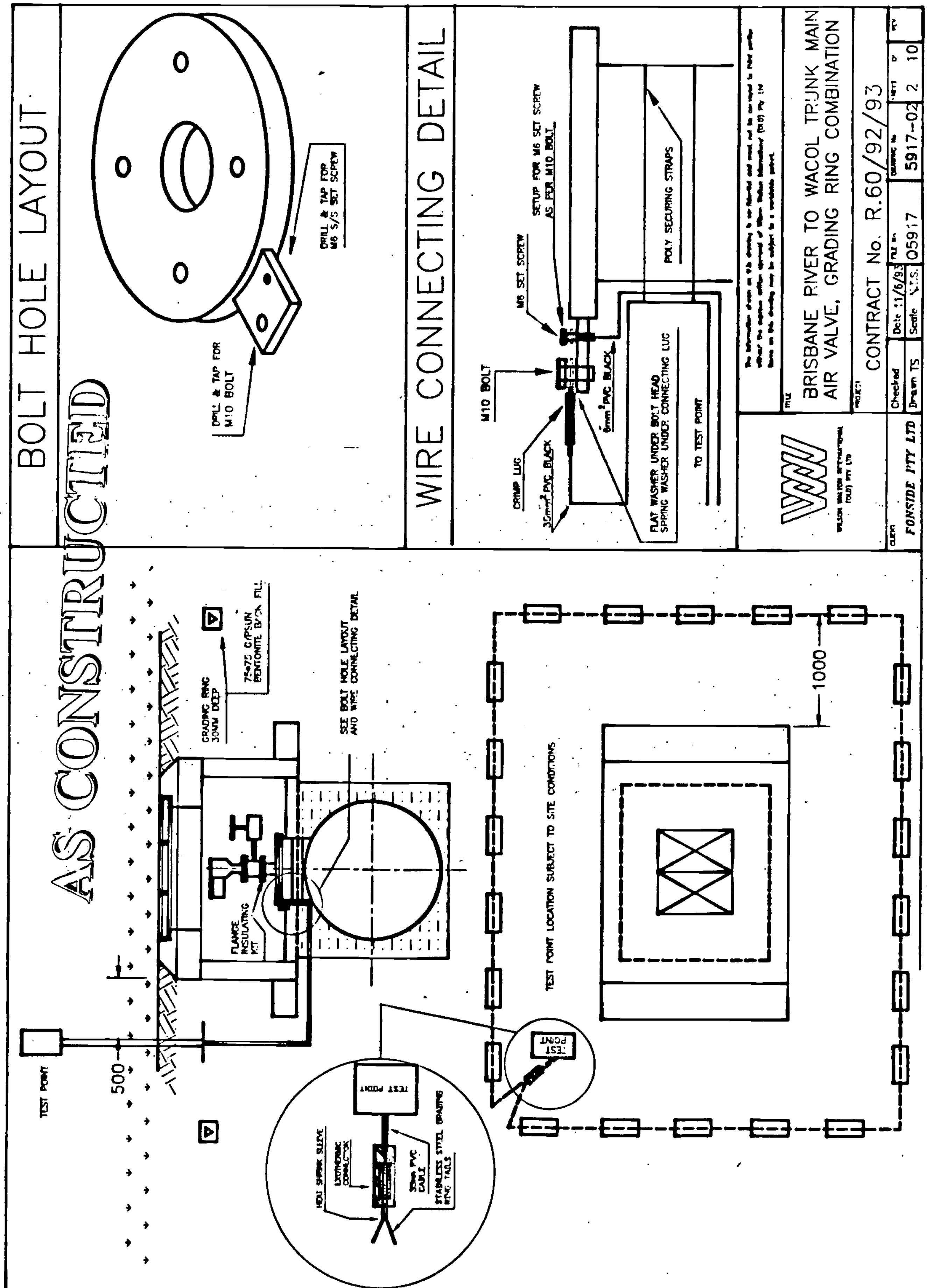
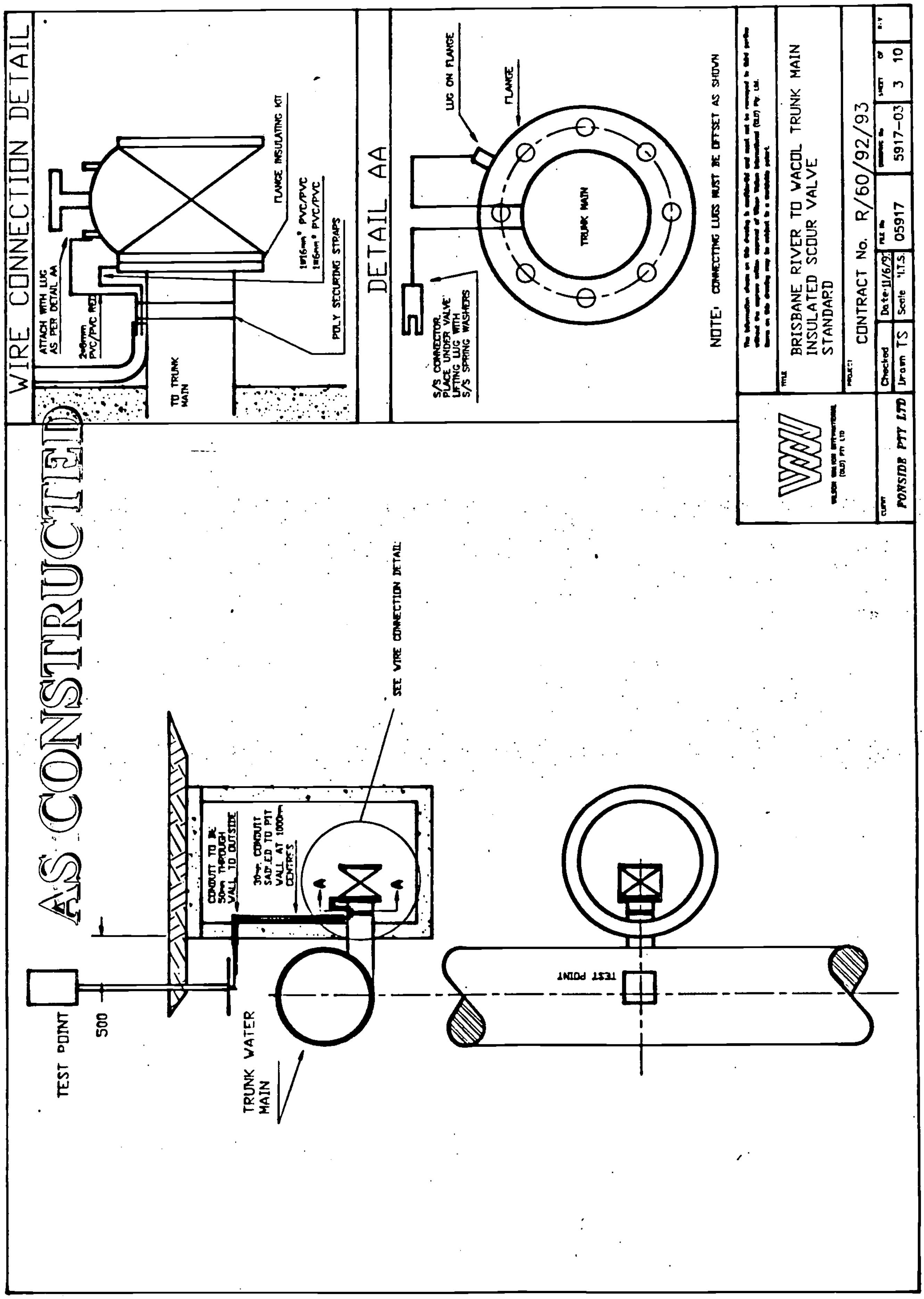
BRISBANE RIVER TO WACOL TRUNK MAIN
ANODE BED LOCATION
CONTRACT No. R.60/92/93
5917-09
9
10
05917
Date 11/6/93
Drawn TS
Scale N.T.S
WACOL STATION ROAD
WACOL STATION ROAD (UNFORMED)
CABLE TRENCH
100m
CREEK
TEST POINT WIRES TO CAST IRON MAIN

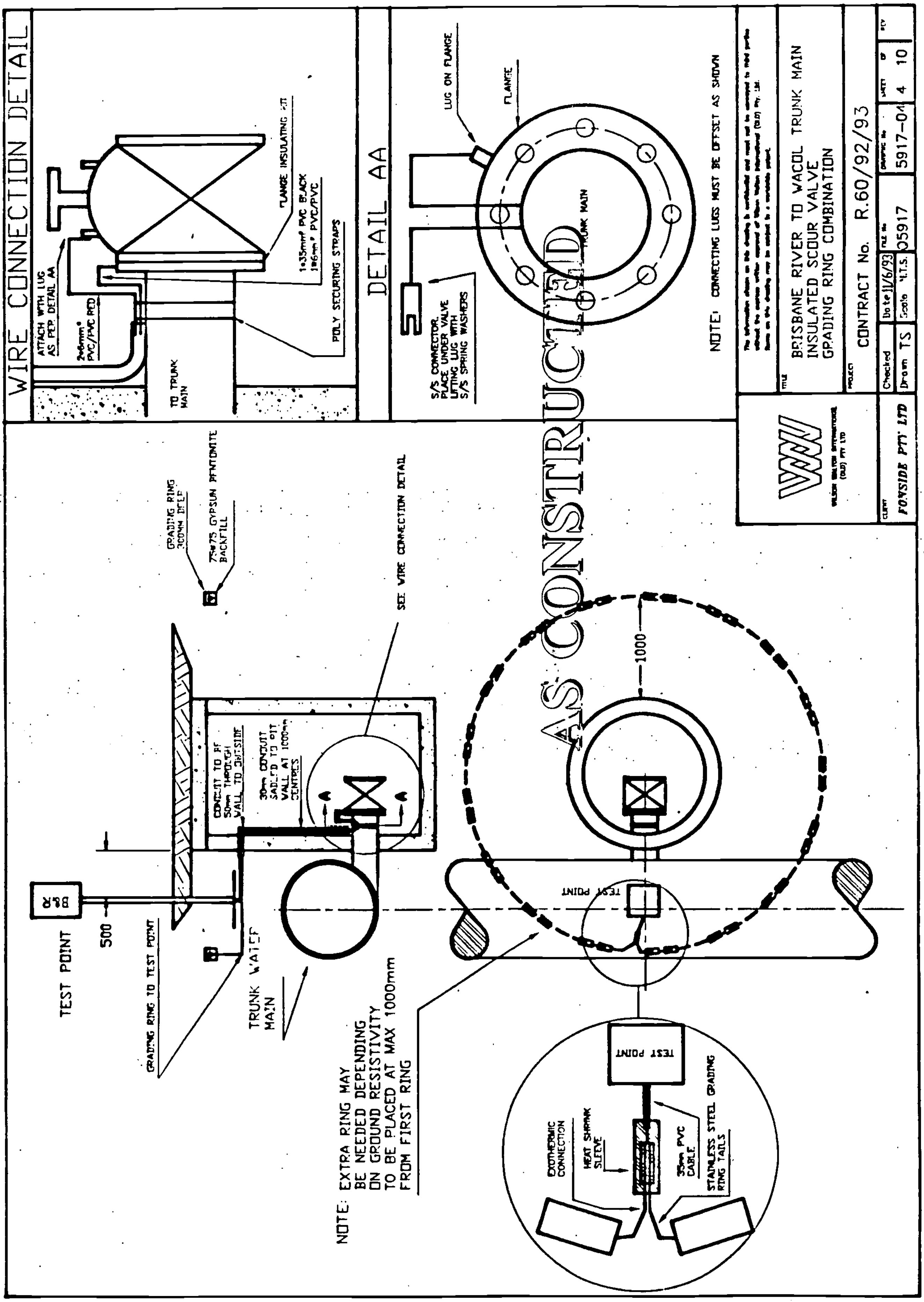

CU STRIP
A1
A2
A3
POSITIVE TO T/R
TYPE B/B TERMINATION BOX
REFER DETAIL B FOR CONNECTION DETAILS
NATURAL BACKFILL TO BEDING SAND
CABLE MARKER TAPE
CABLE TO HAVE 50mm BEDDING SAND EACH SIDE OR 50mm PVC CONDUIT
CABLE TRENCH DETAIL
TRUNK MAIN
CABLE IN TRENCHES 600 MIN DEPTH
AC POWER
CORROSION COUPON
ZINC REFERENCE CELL
REFER DRAWING "ANODE BED LOCATION" FOR LOCATION DETAILS
TRANSFORMER RECTIFIER UNIT
TYPE B/B TERMINATION BOX
25mm² PVC/PVC (RED COVER) ANODE BED HEADER CABLE
CONSOLIDATED BACKFILL FREE OF ROCKS
CABLE MARKER TAPE
50Φ x 1500mm Si Fe Cr ANODES 16mm² POLY/POLY
METALLURGICAL COKE BREEZE
WELDED TYPE MANHOLE
TRUNK MAIN
DETAIL B CONNECTION DETAIL
FOR CONNECTION DETAIL REFER AP VALVE STANDARD DRAWING
1x4mm² PVC YELLOW
ZINC REFERENCE CELL
CORROSION COUPON
600
300
300
400
2000
ANODE BED DETAIL
BRISBANE RIVER TO WACOL TRUNK MAIN
STANDARD ANODE BED DETAILS
CONTRACT No. R.60/92/93
WILSON WALTON INTERNATIONAL (QLD) PTY LTD
FONSIDE PTY LTD
Checked
Drawn TS
Date 11/6/93
Scale N.T.S.
Q5917
5917-10
10 10
AS CONSTRUCTED


BOLT HOLE LAYOUT
DRILL & TAP FOR M10 BOLT
DRILL & TAP FOR M6 S/S SET SCREW
WIRE CONNECTING DETAIL
M10 BOLT
M6 SET SCREW
SETUP FOR M6 SET SCREW AS PER M10 BOLT
POLY SECURING STRAPS
CRIMP LUG
35mm² PVC BLACK
6mm² PVC BLACK
FLAT WASHER UNDER BOLT HEAD
SPRING WASHER UNDER CONNECTING LUG
TO TEST POINT
WILSON WALTON INTERNATIONAL (QLD) PTY LTD
BRISBANE RIVER TO WACOL TRUNK MAIN
AIR VALVE STANDARD
CONTRACT No. R.60/92/93
Q5917
5917-0
1
10
N.T.S.
FONSIDE PTY LTD
TEST POINT
500
FLANGE INSULATING KIT
SEE BOLT HOLE LAYOUT AND WIRE CONNECTING DETAIL
TEST POINT LOCATION SUBJECT TO SITE CONDITIONS
AS CONSTRUCTED

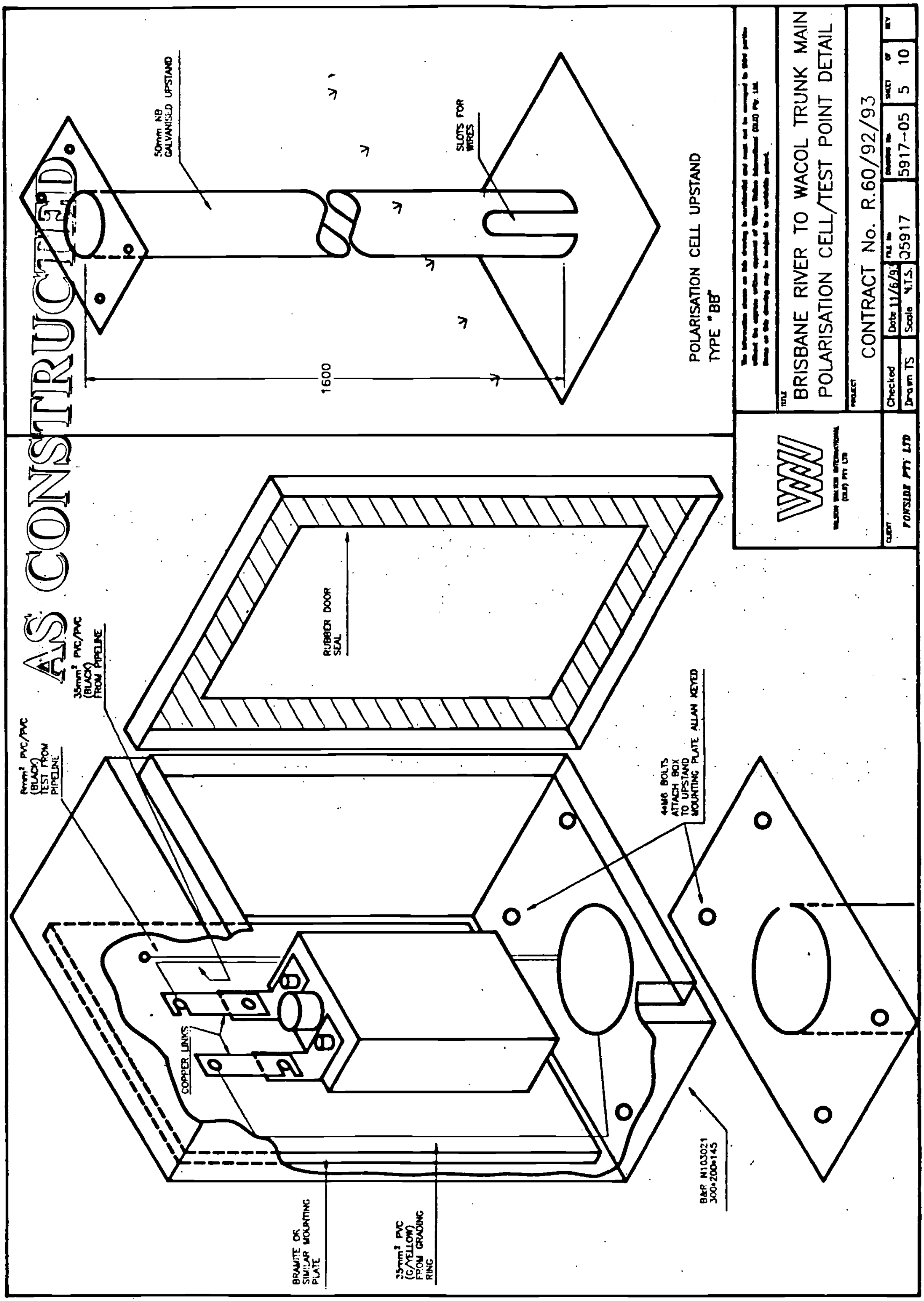

BOLT HOLE LAYOUT
DRILL & TAP FOR M10 BOLT
DRILL & TAP FOR M6 S/S SET SCREW
WIRE CONNECTING DETAIL
M10 BOLT
CRIMP LUG
35mm² PVC BLACK
6mm² PVC BLACK
M6 SET SCREW
SETUP FOR M6 SET SCREW AS PER M10 BOLT
POLY SECURING STRAPS
FLAT WASHER UNDER BOLT HEAD
SPRING WASHER UNDER CONNECTING LUG
TO TEST POINT
AS CONSTRUCTED
TEST POINT
500
GRADING RING 30MM DEEP
75-75 GYPSUM BENTONITE BACK FILL
SEE BOLT HOLE LAYOUT AND WIRE CONNECTING DETAIL
FLANGE INSULATING KIT
TEST POINT LOCATION SUBJECT TO SITE CONDITIONS
1000
HEAT SHRINK SLEEVE
EXOTHERMIC CONNECTOR
35mm PVC CABLE
STAINLESS STEEL GRADING RING TAILS
BRISBANE RIVER TO WACOL TRUNK MAIN
AIR VALVE, GRADING RING COMBINATION
CONTRACT No. R.60/92/93
FONSIDE PTY LTD
Checked
Drawn TS
Date 11/6/93
Scale N.T.S.
05917
5917-02
2
10

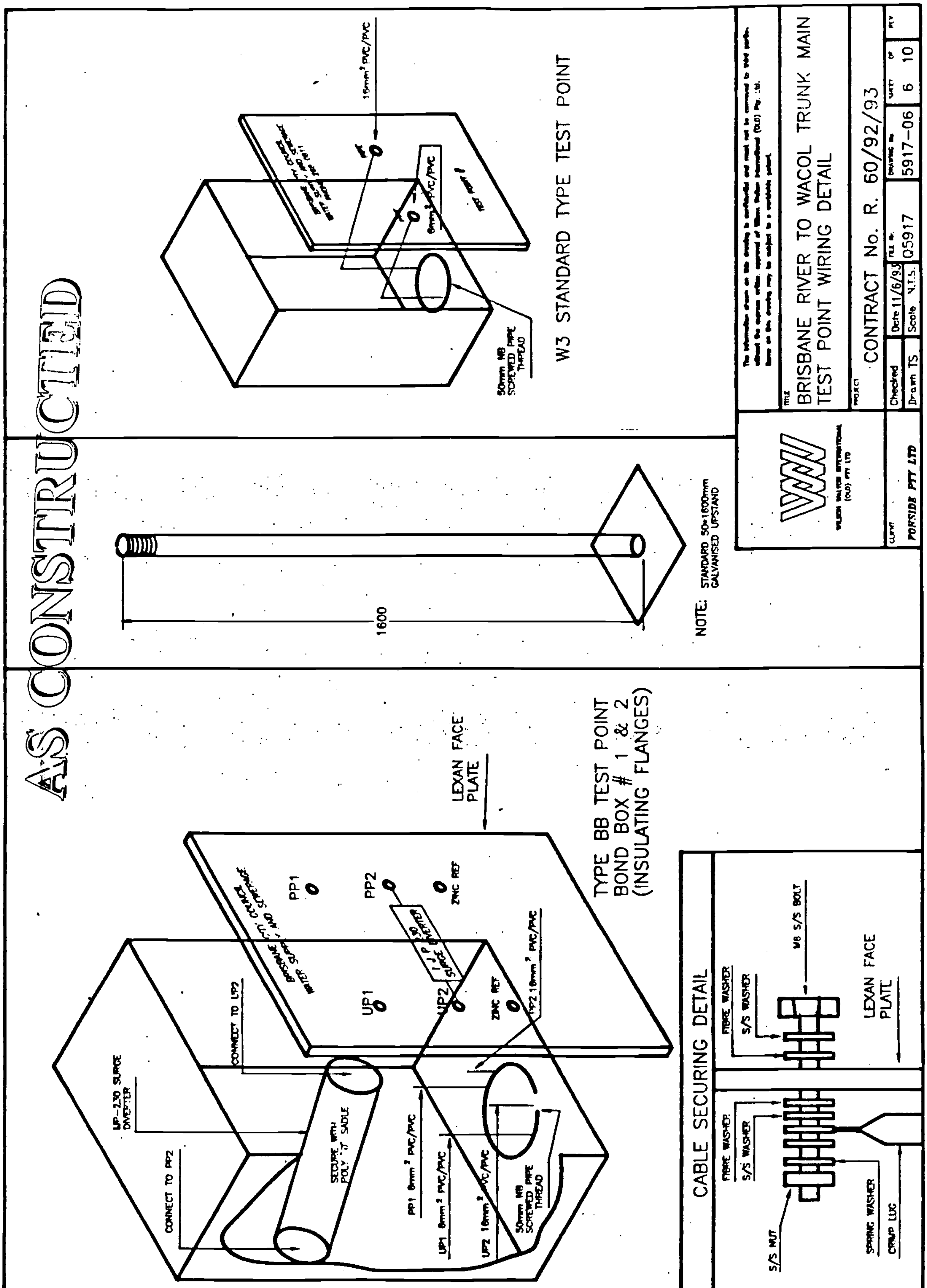


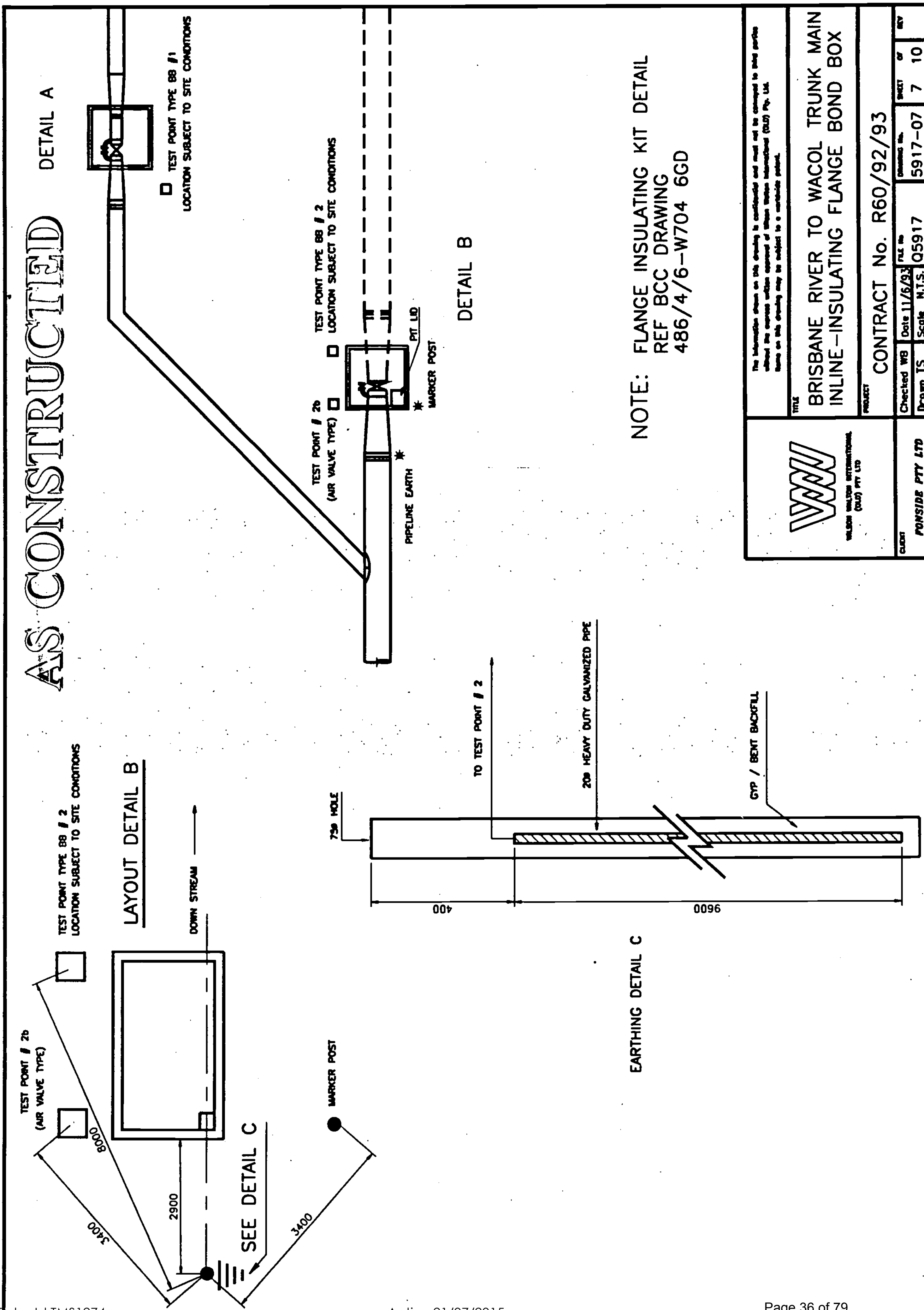
WIRE CONNECTION DETAIL
ATTACH WITH LUG AS PER DETAIL AA
2x6mm PVC/PVC RED
FLANGE INSULATING KIT
1x16mm² PVC/PVC
1x6mm² PVC/PVC
POLY SECURING STRAPS
TO TRUNK MAIN
DETAIL AA
LUG ON FLANGE
FLANGE
TRUNK MAIN
S/S CONNECTOR. PLACE UNDER VALVE LIFTING LUG WITH S/S SPRING WASHERS
NOTE: CONNECTING LUGS MUST BE OFFSET AS SHOWN
BRISBANE RIVER TO WACOL TRUNK MAIN
INSULATED SCOUR VALVE
STANDARD
CONTRACT No. R/60/92/93
5917-03
3
10
05917
Date 11/6/93
Scale N.T.S.
Drawn TS
PONSIDE PTY LTD
AS CONSTRUCTED
SEE WIRE CONNECTION DETAIL
CONDUIT TO BE 50mm THROUGH WALL TO OUTSIDE
30mm CONDUIT SADDLED TO PIT WALL AT 1000mm CENTRES
TEST POINT
500
TRUNK WATER MAIN
TEST POINT

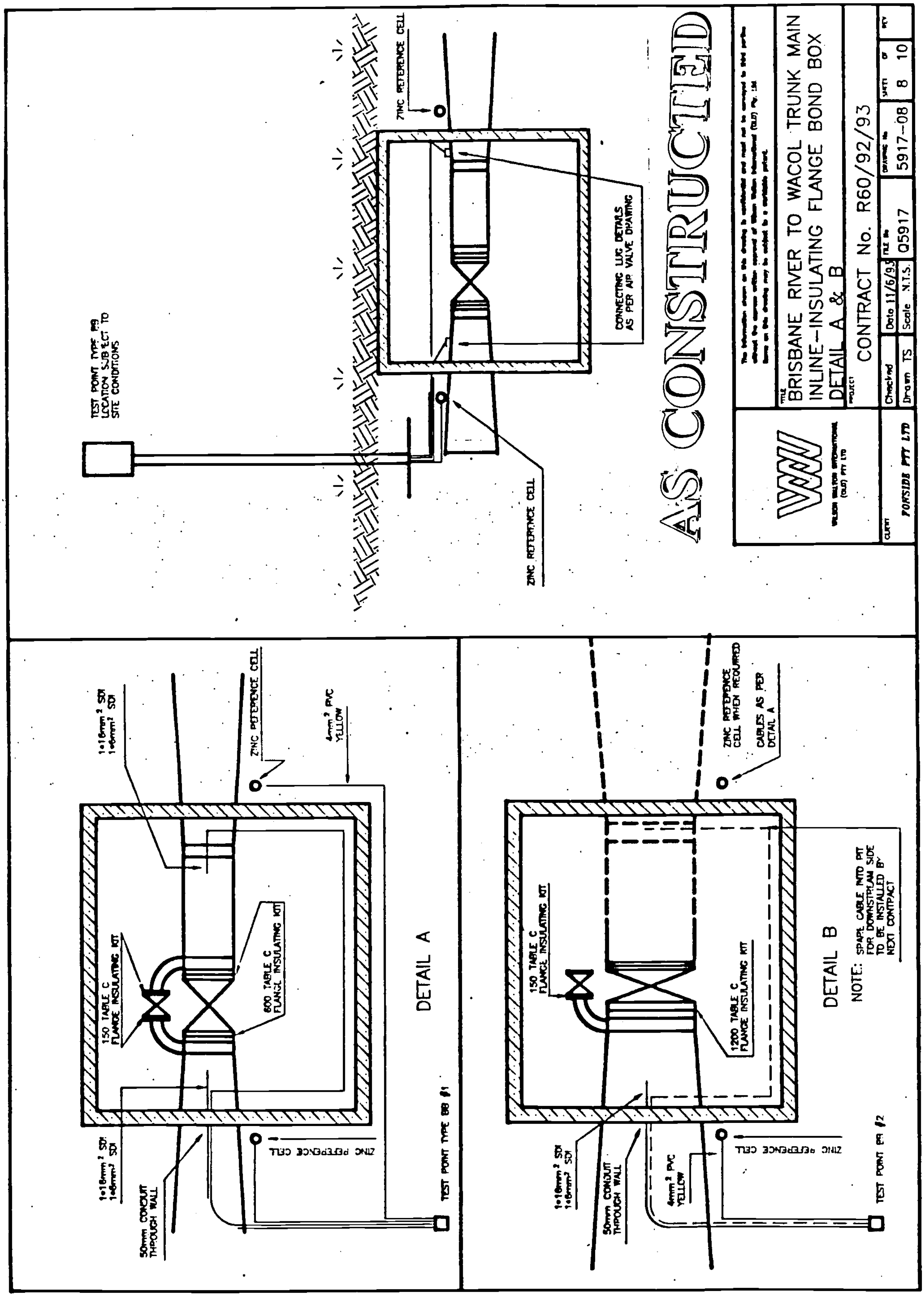


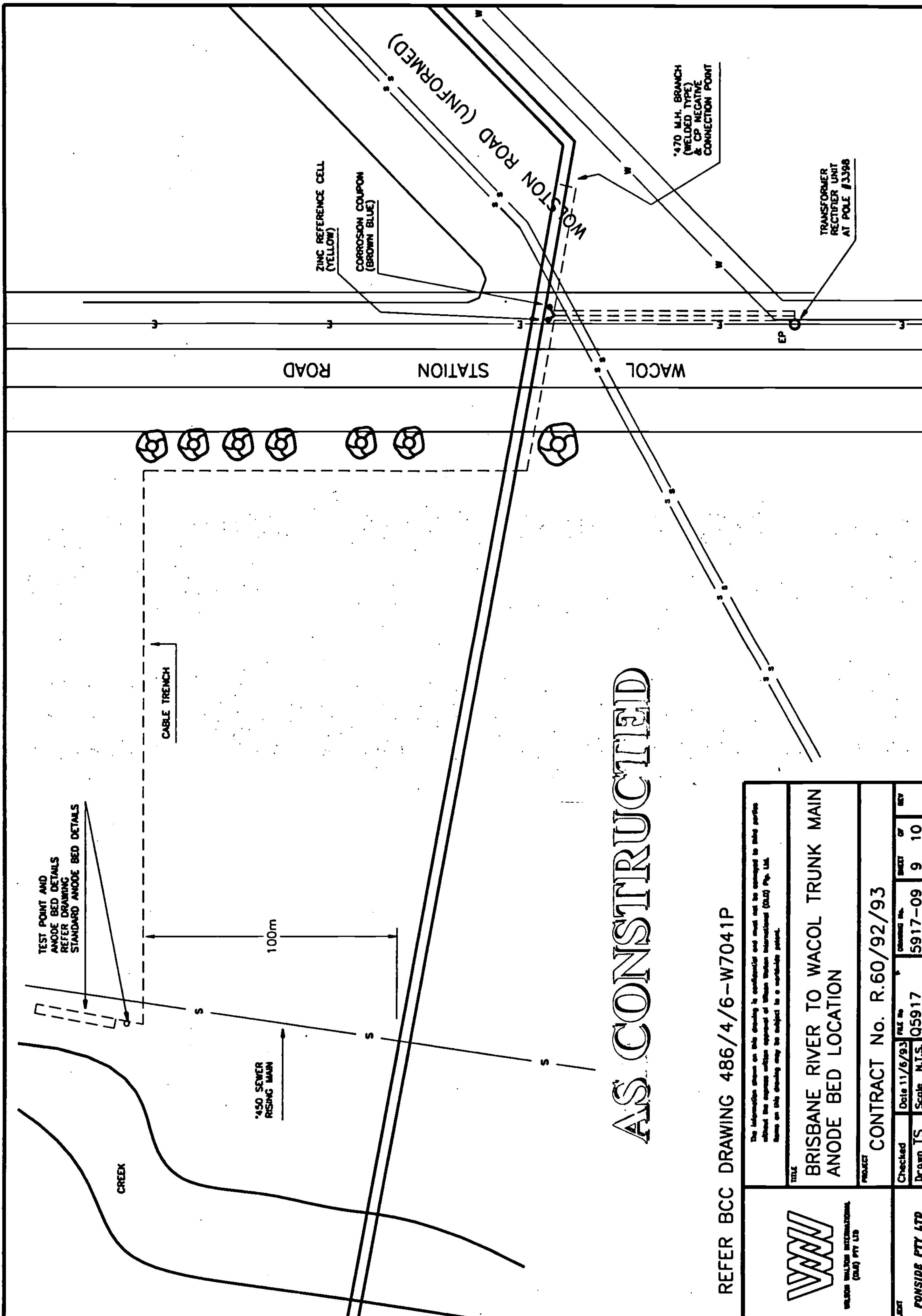
WIRE CONNECTION DETAIL
ATTACH WITH LUG AS PER DETAIL AA
2x6mm² PVC/PVC RED
TO TRUNK MAIN
FLANGE INSULATING KIT
1x35mm² PVC BLACK
1x6mm² PVC/PVC
POLY SECURING STRAPS
DETAIL AA
LUG ON FLANGE
FLANGE
TRUNK MAIN
S/S CONNECTOR. PLACE UNDER VALVE LIFTING LUG WITH S/S SPRING WASHERS
NOTE: CONNECTING LUGS MUST BE OFFSET AS SHOWN
BRISBANE RIVER TO WACOL TRUNK MAIN
INSULATED SCOUR VALVE
GRADING RING COMBINATION
CONTRACT No. R.60/92/93
Date 11/6/93
Scale N.T.S.
05917
5917-04
4
10
Drawn TS
FOXSIDE PTY LTD
AS CONSTRUCTED
GRADING RING 300MM DEEP
75x75 GYPSUM BENTONITE BACKFILL
SEE WIRE CONNECTION DETAIL
CONDUIT TO BE 50mm THROUGH WALL TO OUTSIDE
30mm CONDUIT SADDLED TO PIT WALL AT 1000mm CENTRES
B&R
TEST POINT
500
GRADING RING TO TEST POINT
TRUNK WATER MAIN
1000
TEST POINT
NOTE: EXTRA RING MAY BE NEEDED DEPENDING ON GROUND RESISTIVITY TO BE PLACED AT MAX 1000mm FROM FIRST RING
EXOTHERMIC CONNECTION
HEAT SHRINK SLEEVE
35mm PVC CABLE
STAINLESS STEEL GRADING RING TAILS

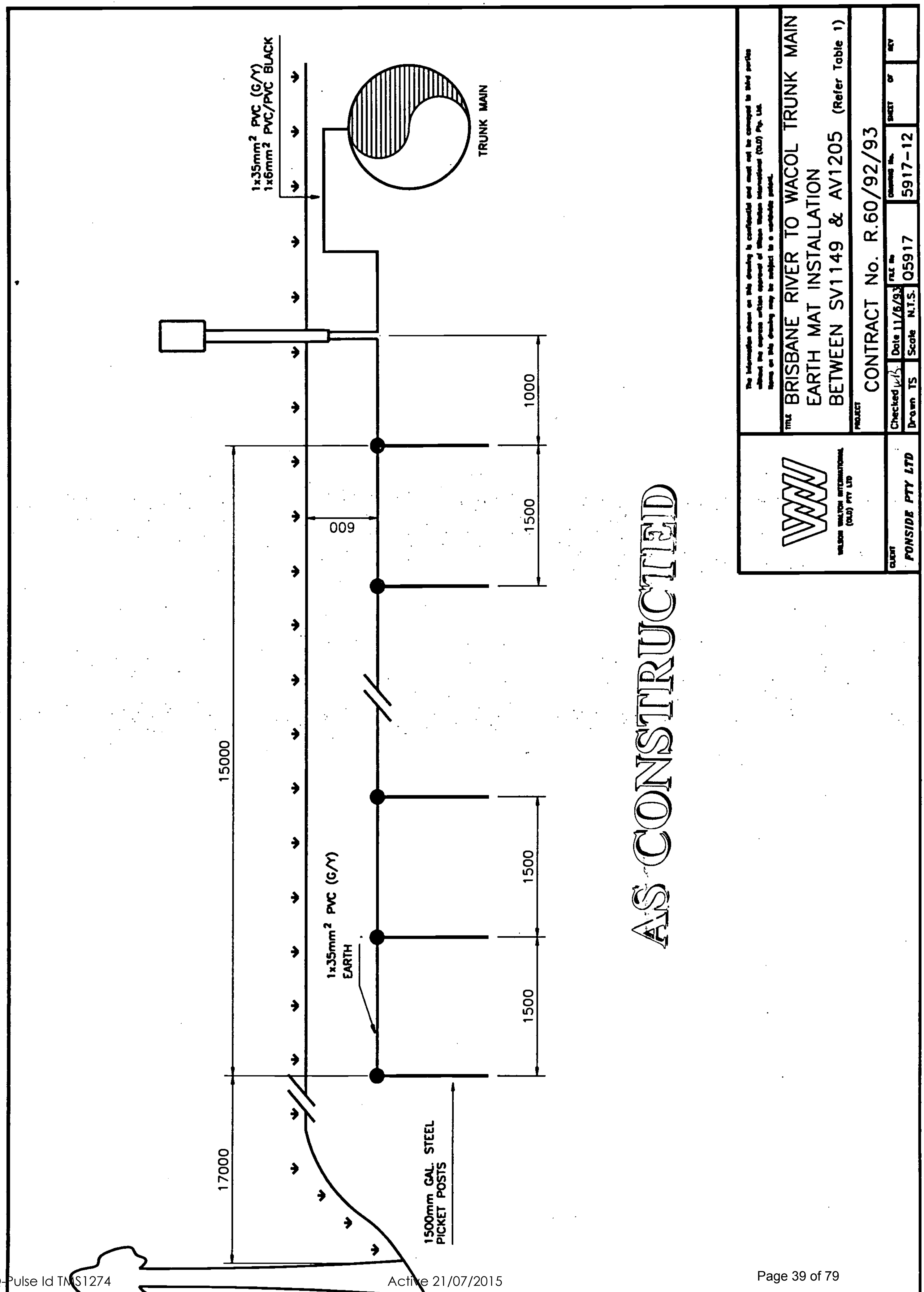

AS CONSTRUCTED
8mm² PVC/PVC (BLACK) TEST FROM PIPELINE
35mm² PVC/PVC (BLACK) FROM PIPELINE
COPPER LINKS
BRAMITE OR SIMILAR MOUNTING PLATE
35mm² PVC (G/YELLOW) FROM GRADING RING
RUBBER DOOR SEAL
4×M6 BOLTS ATTACH BOX TO UPSTAND MOUNTING PLATE ALLAN KEYED
B&R N103021 300×200×145
50mm NB GALVANISED UPSTAND
1600
SLOTS FOR WIRES
POLARISATION CELL UPSTAND TYPE "BB"
WILSON WALTON INTERNATIONAL (QLD) PTY LTD
TITLE
BRISBANE RIVER TO WACOL TRUNK MAIN
POLARISATION CELL/TEST POINT DETAIL
PROJECT
CONTRACT No. R.60/92/93
CLIENT
PONSIDE PTY LTD
Checked
Drawn TS
Date 11/6/93
Scale N.T.S.
FILE No
05917
DRAWING No.
5917-05
SHEET
5
OF
10
REV


AS CONSTRUCTED
W3 STANDARD TYPE TEST POINT
15mm² PVC/PVC
6mm² PVC/PVC
50mm NB SCREWED PIPE THREAD
1600
NOTE: STANDARD 50x1600mm GALVANISED UPSTAND
TYPE BB TEST POINT BOND BOX # 1 & 2 (INSULATING FLANGES)
LEXAN FACE PLATE
PP1
PP2
ZINC REF
UP1
UP2
CONNECT TO UP2
UP-230 SURGE DIVERTER
SECURE WITH POLY 'T' SADLE
CONNECT TO PP2
PP1 6mm² PVC/PVC
UP1 6mm² PVC/PVC
UP2 16mm² PVC/PVC
CABLE SECURING DETAIL
FIBRE WASHER
S/S WASHER
M8 S/S BOLT
S/S NUT
SPRING WASHER
CRIMP LUG
LEXAN FACE PLATE
WILSON WALTER INTERNATIONAL (QLD) PTY LTD
CLIENT PORTSIDE PTY LTD
TITLE BRISBANE RIVER TO WACOL TRUNK MAIN TEST POINT WIRING DETAIL
PROJECT CONTRACT No. R. 60/92/93
Checked
Drawn TS
Date 11/6/93
Scale N.T.S.
File No. Q5917
Drawing No. 5917-06
Sheet 6 of 10


AS CONSTRUCTED
DETAIL A
TEST POINT TYPE BB # 1
LOCATION SUBJECT TO SITE CONDITIONS
DETAIL B
TEST POINT TYPE BB # 2
LOCATION SUBJECT TO SITE CONDITIONS
TEST POINT # 2b
(AIR VALVE TYPE)
PIT LID
MARKER POST
PIPELINE EARTH
NOTE: FLANGE INSULATING KIT DETAIL
REF BCC DRAWING
486/4/6-W704 6GD
LAYOUT DETAIL B
TEST POINT TYPE BB # 2
LOCATION SUBJECT TO SITE CONDITIONS
TEST POINT # 2b
(AIR VALVE TYPE)
DOWN STREAM
MARKER POST
SEE DETAIL C
8000
3400
2900
3400
TO TEST POINT # 2
20Ø HEAVY DUTY GALVANIZED PIPE
GYP / BENT BACKFILL
75Ø HOLE
400
9600
EARTHING DETAIL C
BRISBANE RIVER TO WACOL TRUNK MAIN
INLINE-INSULATING FLANGE BOND BOX
CONTRACT No. R60/92/93
Checked WB
Drawn TS
Date 11/6/93
Scale N.T.S.
Q5917
5917-07
7
10
PONSIDE PTY LTD


AS CONSTRUCTED
ZINC REFERENCE CELL
CONNECTING LUG DETAILS AS PER AIR VALVE DRAWING
LOCATION SUBJECT TO SITE CONDITIONS
ZINC REFERENCE CELL
BRISBANE RIVER TO WACOL TRUNK MAIN
INLINE-INSULATING FLANGE BOND BOX
DETAIL A & B
CONTRACT No. R60/92/93
Checked
Date 11/6/93
Drawn TS
Scale N.T.S.
Q5917
5917-08
8
10
1x16mm² SDI
1x6mm² SDI
ZINC REFERENCE CELL
4mm² PVC YELLOW
150 TABLE C FLANGE INSULATING KIT
600 TABLE C FLANGE INSULATING KIT
DETAIL A
50mm CONDUIT THROUGH WALL
ZINC REFERENCE CELL
ZINC REFERENCE CELL WHEN REQUIRED
CABLES AS PER DETAIL A
150 TABLE C FLANGE INSULATING KIT
1200 TABLE C FLANGE INSULATING KIT
DETAIL B
NOTE: SPARE CABLE INTO PIT FOR DOWNSTREAM SIDE TO BE INSTALLED BY NEXT CONTRACT
1x16mm² SDI
1x6mm² SDI
50mm CONDUIT THROUGH WALL
4mm² PVC YELLOW
ZINC REFERENCE CELL


WOLSTON ROAD (UNFORMED)
*470 M.H. BRANCH (WELDED TYPE) & CP NEGATIVE CONNECTION POINT
TRANSFORMER RECTIFIER UNIT AT POLE #1398
ZINC REFERENCE CELL (YELLOW)
CORROSION COUPON (BROWN BLUE)
WACOL STATION ROAD
EP
CABLE TRENCH
TEST POINT AND ANODE BED DETAILS REFER DRAWING STANDARD ANODE BED DETAILS
100m
*450 SEWER RISING MAIN
CREEK
AS CONSTRUCTED
REFER BCC DRAWING 486/4/6-W7041P
WILSON WALTON INTERNATIONAL (QLD) PTY LTD
TITLE
BRISBANE RIVER TO WACOL TRUNK MAIN
ANODE BED LOCATION
PROJECT
CONTRACT No. R.60/92/93
Checked
Drawn TS
Date 11/6/93
Scale N.T.S.
Q5917
5917-09
9
10
CLIENT
PONSIDE PTY LTD


1x35mm² PVC (G/Y)
1x6mm² PVC/PVC BLACK
TRUNK MAIN
1000
1500
600
15000
1500
1500
1x35mm² PVC (G/Y)
EARTH
17000
1500mm GAL. STEEL PICKET POSTS
AS CONSTRUCTED
BRISBANE RIVER TO WACOL TRUNK MAIN
EARTH MAT INSTALLATION
BETWEEN SV1149 & AV1205 (Refer Table 1)
CONTRACT No. R.60/92/93
WILSON WALTON INTERNATIONAL (QLD) PTY LTD
PONSIDE PTY LTD
Checked
Date 11/6/93
Drawn TS
Scale N.T.S.
Q5917
5917-12

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APPENDIX III

BRISBANE CITY COUNCIL

LOGAN CITY TRUNK MAIN

WACOL - BRISBANE RIVER

CONTRACT No. R60-92/93

COMMISSIONING REPORT

CATHODIC PROTECTION

WWI Reference Number: Q5917
WWI Document Number: 320584

Prepared by: W. A. R. Burns
Approved by: W. A. R. Burns

WILSON WALTON

CONTENTS

WILSON WALTON

1.0 SUMMARY

The cathodic protection system installed under Contract No. R60-92/93 is operating satisfactorily with pipeline potential levels being maintained within the as specified range of -0.85 to -1.2 volts versus a copper/copper sulphate reference electrode.

The cathodic protection current from the impressed current cathodic protection unit required to achieve an average potential of -950mV was 60 milliamps. No adverse effects on adjacent structures was found as a result of commissioning at an initial current output of 1.0 Amps.

2.0 INTRODUCTION

As part of the Contract No. R60-92/93, Wilson Walton International (QLD) Pty Ltd conducted commissioning works associated with the impressed current cathodic protection system installed on the Wacol - Brisbane River Section of the Logan City Trunk Main Water Supply Pipeline.

Final system commissioning was undertaken during November, 1993 following the installation of the impressed current cathodic protection system in conjunction with interference testing. The purpose of the survey was to establish the following:

i) Carry out testing of the cathodic protection system and associated equipment.

ii) Determine the degree of cathodic protection being maintained on the buried sections of the pipeline and note any requirements for adjustments, modifications or repairs to the system considered necessary to maintain an adequate degree of protection on the pipeline.

iii) Carry out confirmatory testing to ensure that the pipeline was electrically isolated at the extremities of buried sections.

iv) Report on any abnormalities relating to corrosion protection and general operation and safety of the pipeline/s and make recommendations, where required, for the continued satisfactory operation of the cathodic protection system.

3.0 COMMISSIONING TESTS

3.1 Pipeline Potentials

Prior to energising the cathodic protection systems, a pipeline to soil potential survey was conducted to monitor the natural potentials along the pipeline/s route.

Following energisation of the system, the output of the cathodic protection transformer rectifier unit was adjusted to levels considered suitable to permit the pipeline to soil potentials to fall within the as specified limits as nominated in the specification. ie. An "instant off" potential of -0.85V (min) -1.2V (max) versus a copper/copper sulphate reference electrode.

In order to license the pipeline with QEC for an output up to 1.0 Amp capacity, commissioning tests were carried out at 1.0 Amp output. The output was later reduced to 60 milliamps (Ma) so as to reduce the operating potentials to an acceptable level (as per the specification).

3.2 Insulating Flanges

During on/off potential testing, integrity of all insulating flanges was confirmed by measuring the potential swing on each side of the insulating fittings.

3.3 Groundbed Resistance

The loop resistance of the groundbed was monitored via measurements of the voltage and associated current outputs in increments. The gradient of a plot of voltage versus current output represents the loop resistance of each system.

3.4 Permanent Earth - Resistance to Earth

The permanent earth installed on the pipeline was subjected to earth resistance testing as required. Testing was conducted via the 2 pin Meggar Earth Testing procedure to remote earth in accordance with AS1768.

3.0 COMMISSIONING CONT'D

3.5 Foreign Structure

Interference to foreign structures was monitored via the measurement of potential swing during On/Instant Off potential measurements. Testing was undertaken on the adjacent SEC high tension tower as well as SEQEB earths, property fences and Telecom cabling in the area.

3.6 Low Frequency Induced Voltage Study

Due to the close proximity of the Queensland Electricity Commission, high tension power lines to the pipeline an induced voltage study was undertaken. The study was commissioned to determine the possibility of hazardous voltages being induced onto the pipeline in the event of an earth current fault occurring on the high tension power lines (Refer to Appendix IV for report data).

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4.0 TEST INSTRUMENTATION

4.1 Pipeline to Soil Potentials

All pipeline to soil potentials were monitored using an M.C. Miller LC-4 digital corrosion voltmeter with a variable input resistance of 10-200 megohm in conjunction with an M.C. Miller RE5C copper/copper sulphate reference electrode.

4.2 Earth Resistance Measurement

Permanent Earth bed earth resistance measurements were conducted using a Nilsson 400 megger 4 pin earth resistance meter.

5.0 RESULTS OF COMMISSIONING TESTING

Refer to Appendix 1 for commissioning results.

6.0 DISCUSSION OF RESULTS

6.1 Pipeline to Soil Potentials

As shown by Appendix I, full cathodic protection of the pipeline within the range of the intended protection levels is provided with potentials being more negative than -0.85V and less than -1.2V versus a copper/copper sulphate reference electrode.

6.2 Insulating Fittings

Potential measurements across insulating fittings confirm that satisfactory electrical isolation of the protected pipeline from structures not requiring protection has been achieved.

6.3 Groundbed Resistance

A loop resistance of 1.6 ohms for the impressed current anode bed confirms that the installation has been completed in a satisfactory manner and within the design requirements.

6.4 Permanent Earth Installation - Resistance

As shown by Appendix 2, the resistance to remote earth of the permanent earth is below the nominated 2.0 ohms.

6.5 Foreign Structures

Appendix 2 indicates that no interference to the high tension transmission tower footings and earths was detected.

6.0 DISCUSSION CONT'D

In addition to the high tension transmission towers, testing was conducted on low voltage power earths as well as Telecom cabling in the vicinity of the pipeline. In both instances, no adverse effects were monitored on any of the structures nominated in the area.

6.6 Low Frequency Induced Voltage Study

As detailed in Appendix IV, the induced voltage study, did conclude that in the event of an earth current fault on the high tension power lines hazardous voltages could be induced onto the water main. The report recommended the installation of an additional earthing electrode at the Tie-In Pit 1 (Wacol end). This electrode was installed at Tie-in Pit 1. An earth resistance reading of 1.1 ohms for this electrode has been accepted as satisfactory to negate the effect of hazardous induced voltages.

6.7 General

6.7.1 Pipeline Electrical Isolation.

The electrical isolation of the pipeline from structures not requiring protection (including scour and air valves) is achieved by the installation of flange insulating gasket kits in all circumstances.

6.7.2 Permanent Reference Cell Installations.

As shown in Appendix 1, the permanent zinc reference electrodes show some small variation when monitored against a standard copper/copper sulphate reference electrode. However, since the permanent cells are used purely as a reference to control the output of the automatic systems of both cathodic protection installation and monitor protection levels on the pipeline, such variation is not unacceptable providing a consistent potential level is maintained.

Similarly, the permanent zinc reference electrodes at each end of the pipeline are used to monitor the potential levels on the pipeline. However, the potential variation in cells relative to a portable copper/copper sulphate reference electrode allows the cells to be calibrated and in a pure sense, then allows for the variation to be accounted for in interpretation of the overall readings.

6.7.3 Corrosion Coupons

The potential testing of the corrosion coupon with the cathodic protection system connected to the coupon and switching on and off indicates polarisation occurring on the coupon soon after the system was commissioned.

6.7.4 Grading Ring Potentials.

As shown by Appendix 2, all the potentials associated with grading rings indicate that consumption of the zinc grading rings via galvanic dissolution is unlikely.

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7.0 CONCLUSIONS & RECOMMENDATIONS

The commissioning works indicate that the cathodic protection system is operating satisfactorily with potential levels maintained within the specified limits of -0.85 to -1.2 volts versus a copper/copper sulphate reference electrode.

Potential testing also confirms that insulating flanges fitted to all of the branches and extremities of the pipeline contract are performing satisfactorily and as such isolating the pipeline from poorly coated sections of associated fittings and/or attachments.

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APPENDIX I

Tables 1 - 4

WILSON WALTON

TABLE 1: RESULTS OF POTENTIAL TESTING (COMMISSIONING)

TP	Location	Nat'al Pot'al	'ON' Pot'al (@ 1 amp)	Instant off Pot'al (Cu/CuSO4)	Insulating Flanges	Remarks
1.	Tie-in Pit 1	0.678	1.418	1.240	-	
2.	Main Pit	0.692	1.470	1.279	0.502	
2a.	AV					Air valve adjacent to main pit TP2
3.	AV 1212	0.680	1.423	1.212	0.460	
T/R.		0.680	1.435	1.248		
4.	SV 1155	0.680	1.435	1.248	0.459	
5.	AV 1211	0.680	1.452	1.257	0.415	
6.	SV 1154	0.680	1.440	1.286	0.300	
7.	AV 1210	0.673	1.444	1.245	0.329	
8.	SV 1153	0.680	1.444	1.293	0.150	
9.	AV 1209	0.663	1.430	1.301	0.290	
10.	SV 1152	0.658	1.434	1.316	0.592	
11.	AV 1208	0.666	1.426	1.246	0.400	
12.	SV 1151	0.675	1.430	1.262	0.419	
13.	AV 1207	0.666	1.430	1.268	0.320	
14.	SV 1150	0.670	1.430	1.264	0.369	
15.	AV 1206	0.661	1.420	1.238	0.360	
16.	SV 1149	0.667	1.416	1.298	0.843	
EARTH MAT					EARTH MAT	
17.	AV 1205	0.663	1.245	1.222	0.420	
18.	AV 1204	0.699	1.386	1.198	-	
19.	SV 1148	0.627	1.402	1.243	1.048	
20.	AV 1203	0.632	1.345	1.225	1.084	
21	OFF TAKE	0.681	1.450	1.369	0.993	
22.	SV 1147	0.629	1.363	1.210	1.022	
23.	SV 1146	0.661	1.345	1.266	0.953	
24.	AV 1202	0.621	1.192	1.174	1.011	
25.	SV 1145	0.627	1.189	1.126	0.968	

NOTE: 1. Potentials are expressed as 'volts negative' with reference to a standard copper/copper sulphate reference electrode.

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TABLE 1B: RESULTS OF POTENTIAL TESTING (28.7.95)

TP	Location	Grading Ring Pot'al	'ON' Pot'al (@ 200mA)	Instant off Pot'al (Cu/CuSO4)	Insulating Flanges	Remarks
1.	Tie-in Pit 1		1.253	1.146	·	
2.	Main Pit		1.270	1.170	(0.502)	
2a.	AV		1.260	1.171	0.620	Air valve adjacent to main pit TP2
3.	AV 1212		1.276	1.180	(0.460)	
T/R.			1.277	1.154		T/R at 2.2V 200mA Output
4.	SV 1155		1.260	1.145	0.692	
5.	AV 1211		1.245	1.160	(0.415)	
6.	SV 1154		1.248	1.140	0.435	
7.	AV 1210		1.259	1.153	(0.329)	
8.	SV 1153		1.260	1.170	0.431	
9.	AV 1209		1.275	1.180	(0.290)	
10.	SV 1152		1.285	1.160	0.603	
11.	AV 1208		1.292	1.180	(0.400)	
12.	SV 1151		1.274	1.162	0.589	
13.	AV 1207		1.281	1.202	(0.320)	
14.	SV 1150		1.284	1.201	0.633	
15.	AV 1206		1.257	1.187	(0.360)	
16.	SV 1149		1.258	1.172	0.588	
EARTH MAT	Earth Mat		1.256	1.173	EARTH MAT	
17.	AV 1205	1.030	1.274	1.190	(0.420)	
18.	AV 1204	1.063	1.265	1.196	·	
19.	SV 1148	1.063	1.076	1.042	0.679	Cell replaced
20.	AV 1203	0.947	1.185	1.090	(1.084)	
21	OFF TAKE		0.847	0.844	0.057	Very dry soil error
22.	SV 1147	1.066	1.239	1.184	0.288	Cell repalced
23.	SV 1146	1.106	1.251	1.184	0.616	
24.	AV 1202	1.034	1.255	1.107	(1.011)	
25.	SV 1145	1.021	1.185	1.087	0.726	

NOTE: 1. Potentials are expressed as 'volts negative' with reference to a standard copper/copper sulphate reference electrode.

NOTE: 2. Earths connected @ TP2 & 16-17. T/R running @ 200mA 2.2 Volts

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TABLE 2: RESULTS OF POTENTIAL TEST - (SET @ 1 AMP OUTPUT & 65 mA)

TP	Location	'ON' Potential	'ON' Pot'al @ 65mA	Remarks
1.	Tie-in Pit 1	1.418	1.002	
2. (T/R)	@ T/R Unit	1.470	1.050	
3.	AV 1212	1.423	0.998	
4.	SV 1155	1.435	1.060	
5.	AV 1211	1.452	1.100	
6.	SV 1154	1.440	1.430	
7.	AV 1210	1.444	1.009	
8.	SV 1153	1.444	1.020	
9.	AV 1209	1.430	1.006	
10.	SV 1152	1.434	1.010	
11.	AV 1208	1.426	1.000	
12.	SV 1151	1.430	0.998	
13.	AV 1207	1.430	0.998	
14.	SV 1150	1.430	0.998	
15.	AV 1206	1.420	0.998	
16.	SV 1149	1.416	0.989	
EARTH Pit #1				
17.	AV 1205	1.245	0.980	
18.	AV 1204	1.386	0.992	
19.	SV 1148	1.402	0.990	
20	AV 1203	1.345	0.990	
21.	OFF TAKE	1.450	0.986	
22.	SV 1147	1.363	0.980	
23.	SV 1146	1.345	0.972	
24.	AV 1202	1.192	1.011	
25	SV 1145	1.189	0.950	

NOTE:
1. Potentials are expressed as 'volts negative' with reference to a standard copper/copper sulphate reference electrode.
2. Initial current setting prior to connection of earthing at Pit Number 1 was 65mA.

TABLE 3: PERMANENT EARTH

Chainage	Location	Resistance to Remote Earth (ohms)
Tie-in Pit 1	Adjacent to Valve Pit	1.1
SV 1148 to AV 1205	Adjacent to CK	1.06

NOTE: 1. Potentials are expressed as 'volts negative' with reference to a standard copper/copper sulphate reference electrode.

TABLE 4: INTERFERENCE TESTING RESULTS QEC TOWERS - T/R @ 1 AMP OUTPUT

Tower No.	Potential Natural	Comments
38 (110 KV)	-0.320	River Crossing
3837 (275 KV)	-0.295	River Crossing
37 (110 KV)	-0.330	River to Switch Yard
3836 (275 KV)	-0.280	River to Switch Yard
Switch Yard	-0.260	Switch Yard
110KV	-0.265	Top of Hill - (Deviation from Pipeline)
275 KV	-0.320	Top of Hill - (Deviation from Pipeline)

NOTE:

1. All four (4) Tower Testings have Similar Potentials.
2. Potentials are expressed as 'volts negative' with reference to a standard copper/copper sulphate reference electrode.

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APPENDIX IV

Low Frequency Induced Voltage Study

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LOW FREQUENCY INDUCTION STUDY

ON

BRISBANE CITY COUNCIL

TRUNK WATER MAIN FROM WACOL TO THE BRISBANE RIVER

by B.M. Byrne

WWI Reference Number: Q5917

BRISBANE CITY COUNCIL
LOGAN CITY TRUNK MAIN - WACOL SECTION
CATHODIC PROTECTION COMMISSIONING REPORT
APRIL 1995

Date: 18/4/95

WWI Document Number: 320584

SECTION 1 - INTRODUCTION

Scope

This study was undertaken to determine the Low Frequency Induction (LFI) effects of the Queensland Electricity Commission (QEC) Extra High Voltage Transmission System on the Trunk Water Main from Wacol to Anstead. The transmission line runs generally parallel to the Water Main over this route. The study has been done in two parts -

Part 1 From Wacol to the Brisbane River

and

Part 2 From the Brisbane River to Anstead.

The river crossing itself is excluded from both parts being separated from both parts by isolation joints in the pipe.

This report deals with the Wacol part.

Because the physical structures, data, fault current and methodology are identical in both parts, the "Introduction" section is the same in both reports.

Recommendations

As a result of this study, the following recommendations are made.

1. That a 1 ohm earth should be installed at the Wacol end of the pipeline capable of carrying 200 amperes for 300 mSec.

2. Never install an access or earth facility to a pipe, cable, or duct within the EPR zone of an electricity Sub Station. As a consequence, the two grading rings at the Darra West Sub Station should be removed and action taken to insulate the valve spindle to avoid operator contact with the pipe.

3. Earth features such as grading rings should not be sited near transmission towers which are linked by the OHEW. It is suggested an isolation figure of 20m might be adopted in future, and a specific distance calculated for each job.

Subject to Recommendations 1 and 2 being adopted, the safety measures are considered adequate.

Foreword

The LFI Study is complicated by a number of factors:

- The QEC Transmission System is comprised of two feeders - one at 275kV and one at 110kV. Both are operated in a mesh mode. Therefore fault current may flow from either end of the feeder to the fault.

In the case of the 110kV feeder this condition will be exacerbated by the presence of the Darra West Sub Station (about midway along the overall pipe route) where fault current may be delivered from any of several feeders from lateral parts of the transmission mesh. As a result, many possible fault current patterns are possible.

- Many earth features (grading rings) have been installed along about three quarters of the pipeline. This makes even reasonably precise calculation of induction levels impossible.

- The pipeline route has some 19 direction changes in its length, some of which involve a crossing with the power transmission lines. This requires the "breaking-up" of the pipe route into 24 segments, followed by individual projection of these on to the transmission line, and calculation for each part.

- The self inductance of the pipe, which is a ferro-magnetic conductor of considerable physical size, is not known. Measurement is of limited accuracy, because of the many earth features. An approximate method has been adopted however, which is considered sufficient for the purpose since it has been applied conservatively.

The study should be read in conjunction with Brisbane City Council Drawing No. 486/4/6 - W7002LO/Amend P2. This scale drawing has been relied on to provide scaled section lengths, directions and offset distances.

The **Study:**

(i) Fault Current Levels

The zero sequence (phase to earth) current levels figures provided by QEC are listed in Appendix 2, Section 6. The calculation is based on a single fault episode, ie it is assumed that two simultaneous faults on the 275kV and 110kV lines (each of which has high speed protection) is so improbable that it may be ignored. In any case, such an unusual event would greatly change the QEC fault current figures.

As noted in the Foreword above, the power transmission systems are mesh. Therefore it is necessary to select possible fault sites, for worst case calculations of the combination of exposure length and current level for such sites.

In the case of the 275kV line, this is relatively simple. This is a fairly high impedance source, and the principal fault current source is from the Karana Sub Station - ie beyond the Anstead pipeline terminal. Thus the maximum LFI effect for this feeder will be for a fault at the Wacol end of the exposure. Also, because the offset distance (pipe to power line) is large at this end - in the order of 500 metres, the coupling factor for this segment will be low. The fault current from Rocklea Sub Station - some 2.46kA at West Darra, would produce a much lower induction figure over the Wacol segment than the 6.4kA at West Darra from Karana. For the Wacol end of the exposure, the projected fault current is calculated to be 6.1kA.

In the case of the 110kV line, there are effectively three fault source Sub Stations - (i) Rocklea, (ii) West Darra, (iii) Ashgrove West. West Darra is in effect a composite source as it is a common point for several feeders.

At Anstead (Mt. Crosby Road), the prospective fault level is 9.24kA from West Darra and 3.64kA from Ashgrove West. Clearly the West Darra feed is the more relevant, as Ashgrove West current would reduce as the fault site moved from Anstead towards the river crossing.

At West Darra Sub Station, the prospective fault current at the Station earth busbar is 17.3kA, of which 2.7kA is from Ashgrove West and 7.8kA from Rocklea. Fault current returns from points adjacent to the Sub Station would depend on the fault mechanism (see below). Fault current delivered by lateral feeders (ie to the south), making up this total, would not have an effect on pipeline LFI. Fault current from West Darra towards Wacol would be 6.64kA at Wacol Station Road. Consequently the fault current in the reverse direction (7.8kA) from Rocklea to West Darra would be the maximum fault current to be considered for LFI calculations.

Before a selection of which fault current is used for calculation, it is necessary to consider the fault mechanisms which might occur.

(ii) Fault Mechanisms

There are several fault mechanisms which will have different effects on the pipeline LFI. The major categories are:

(a) Phase conductor falling to earth - a very rare occurrence. The earth contact resistance limits the fault current from this mechanism. Typically, 10 ohms is a conservative contact figure. This mechanism will be referred to as **Earth Contact.**

(b) Metallic contact between a phase conductor and either a structural support tower or the overhead earth wire (OHEW) which is bonded to the towers. This is the fault current which is quoted by QEC. It is a very uncommon failure mechanism and produces the highest (theoretical) fault current for that line. The OHEW carries a proportion of the fault current return and this proportion is excluded from LFI calculations. This mechanism will be referred to as Tower Contact.

(c) A lightning induced arc, following the rise of potential of a tower due to lightning/attachment to it or the OHEW, and consequent flashover across the insulator string. This results in power line fault current following through the arc path, until the protection sensors trip the high speed circuit breakers (100 mSec for 275kV and 150 mSec for 110kV). This is the most common mechanism with perhaps 2 or 3 events/annum/100km of transmission line. The fault current level is reduced by the impedance of the arc path - about 4 ohms. This mechanism will be referred to as **Lightning Arc.**

The fault currents which flow because of each of these mechanisms may be derived from the current figures provided by QEC as follows -

Calculation to derive Earth Contact current from Tower Contact current for 110kV Line

The listed fault conditions are 110kV/9.24kA

Phase Voltage $= \frac{110}{\sqrt{3}} kv$

$= 63.5kV$ (1)

Phase Impedance $= \frac{63.5kV}{9.24kA}$

$=$ 6.9 ohms (resistive) (2)

At a ground contact resistance of 10 ohms (typical):

Total Impedance (resistive) $= 6.9 + 10\,\Omega$

$=$ 16.9 ohms (resistive)

Earth Contact Fault Current (Direct to Earth)

$= \frac{63.5kV}{16.9 \text{ ohms}}$

$= 3.7kA$ (3)

Calculation to derive Lightning Arc current from Tower Contact current for 110kV Line

Phase impedance $= 6.9\,\Omega$ (From equation 2)

Total impedance = Phase impedance plus arc path

$=$ 6.9 + 4 ohms (arc)

$=$ 10.9 ohms (resistive)

Lightning Arc Current
(to OHEW and Towers) $= \frac{63.5kV}{10.9 \text{ ohms}} kA$ (63.5kV from equation 1)

$=$ 5.8kA (4)

It might be noted that an Earth Contact fault has an immediate effect in earth current coupling, ie the current path is wholly to earth at the fault site. Tower Contact and Lightning Arc faults however place a significant part of the fault current on the OHEW, whence a proportion, decreasing with distance is diverted by successive tower footings to the earth path. This means that something over a kilometre along the route passes, before the "final" proportion between the OHEW and earth path is established. Over this kilometre plus, the LFI effect ranges from near nil at the fault site to the calculated level at the end of this current transfer length. In calculations below, the worst case condition is assumed (ie it is assumed that the fault site is more than a kilometre beyond the exposure).

SECTION 2 THE WACOL EXPOSURE

This section develops the LFI levels which can be expected in the Wacol exposure of the pipeline.

Using the fault currents provided by QEC and the process which was outlined in the discussion on fault mechanisms in the introduction Table 1(W) below sets out the fault currents which can be expected for each of the different fault mechanisms.

	275kV	110kV
QEC Fault Figures	6.1kA (Note 1)	7.8kA
Earth Contact	4.41kA	3.5kA
Tower Contact	6.1kA	7.8kA
Lightning Arc	5.29kA (Note 2)	5.23kA (Note 2)

Note 1 Calculated from QEC figures for Fault at Wacol end of Exposure.
Note 2 This is the most common fault mechanism.

Table 1(W) Fault Currents

Coupling Factors

BCC Scale Drawing No. 486/4/6-W7002LO/P2 depicts the pipeline layout, together with the QEC easement. From this drawing a scaled distance and offset has been made of the twelve variously oriented segments of the pipe.

One of these segments (No. 7) has been further subdivided to cater for coupling factor changes that occur as an offset distance varies by more than x3 in one segment.

These segments have been numbered from the Wacol end of the pipeline with 0-1(1) being the first, then after a direction change 1-2(2) and so on. Sub-divided segments are shown as 7(a), 7(b), 7(c).

The offset distance for calculation of each segment has been derived from the formula $\sqrt{d_1.d_2}$ where d_1 and d_2 are the maximum and minimum offset distances for each segment. A parallel segment has d_1 and d_2 = d. Table 2(W) below sets out the results of this process.

Wacol Section - Starting from Wacol

Segment	Length, Metres	Offset distances, metres (horizontal component)		
		max (d_1)	min (d_2)	d - derived
1 (0-1)	180	450	450	450
2	275	680	500	583
Wacol Station Road				
3	175	675	525	600
4	225	525	500	510
5	280	500	300	387
6	580	300	275	287
QEC Easement				
7(a)	167	275	90	157
7(b)	83	90	30	52
7(c)	28	30	10	17
Crossing 30° to parallel		See Note 1	See Note 1	See Note 1
8	300	30	30	30
9	70	120	30	60
Darra West Sub Station				
10	150	120	30	60
11	120	40	40	40
12	250	30	30	30
Brisbane River				
		end of Section		

Note 1 For crossings within a 10 metre projection parallel to the power line, the approximate induction will be 10V/kA within these parallels (From Appendix 1, Reference 1)

Table 2(W) - Segment Offsets

From Table 2(W) ,the earth resistivities listed in Appendix 2, Reference 4 and by using the process and nomogram given in Appendix 1, Reference 4, it is possible to derive the coupling factor for each segment of the exposure.

Table 3(W) below sets out the results of this process. The resistivities in the table are derived from the test results which are given in Appendix 2, Reference 4.

Segment	Length (m)	Offset (m)	Resistivity Ω/m	Coupling Factor
1	180	450	28	.03
2	275	583	28	.029
3	175	600	28	.029
4	225	510	28	.029
5	280	387	30	.039
6	580	287	30	.05
7(a)	167	157	30	.08
7(b)	83	60 Note 2	30	.135
7(c)	28	35 Note 2	30	.16
Crossing	-	See Note 1	See Note 1	See Note 1
8	300	45 Note 2	30	.155
9	70	67 Note 2	36	.14
10	150	67 Note 2	36	.14
11	120	50 Note 2	36	.15
12	150	45 Note 2	36	.155

Note 1 For crossings within a 10 metre projection parallel to the power line, the approximate induction will be 10V/kA within these parallels and may be treated as an empirical 6m separation (From Appendix 1, Reference 1). Over 45° the level will effectively be zero.

Note 2 Component included for height of transmission line.

Table 3(W) Coupling Factors of Segments in the Wacol Section

The Induction Level

Calculation of the total LFI level on the pipeline is a matter of application of the formula E = CILK from Appendix 1, Reference 5 for each of the segments. Being approximately resistive, these may then be summed. Strictly, there will be a reactive component for Segments 1 to 6, but adding as resistive will produce a conservative result of about 5% (ie higher voltage calculated).

The current (I) to be used in this formula is taken from Table 1(W). The phase conductors are very strong and Earth Contact faults are virtually non-existent in non-cyclone areas. The choice therefore lies between Tower Contact or Lightning Arc fault currents. Tower Contact faults are very rare and therefore the Lightning Arc fault currents will be used in this study. Nevertheless, a comment on the induction from Tower Contact will be offered in the "Discussion" section.

From Table 1(W) it can be seen that the Lightning Arc fault currents for both the 275kV and 110kV feeders are nearly identical - 5.29kA and 5.23kA. The rounded figure of 5.3kA will be used in the calculations which follow.

Each of the 14 segments will be calculated thus:

$$E = C\,I\,L\,K \qquad \text{(Reference 5, Appendix 1)}$$

The coupling factor **C** and the length, **L** (in kilometres) are taken from Table 3(W) above, **I** is 5.3k amps and **K** is the shielding factor.

The shielding factor, supplied by QEC is .77 for the OHEWs. An environmental factor is also appropriate for the built up area of River Hills - Segments 7 to 12. An appropriate figure for this class of suburban development is 0.8. Segments adjacent to the West Darra Sub Station will be much more effectively shielded by the extensive station earths and OHEWs. For these two segments, a shielding multiplier factor of 0.5 will be used. Thus K will range from .77 in undeveloped areas through .62 behind River Hills to .39 at Darra West Sub Station.

The results are as follows:

No. 1 Segment (Sample Calculation)

$$E = C\,I\,L\,K$$
$$= .03 \times 5300 \times .18 \times .77$$
$$= 22 \text{ Volts.}$$

The full table reads:

Segment	C	L (km)	K	E (volts)
1	.03	.18	.77	22
2	.029	.275	.77	33
3	.029	.175	.77	21
4	.029	.225	.77	27
5	.039	.28	.77	44
6	.05	.58	.77	118
7(a)	.08	.167	.77	55
7(b)	.135	.038	.77	46
7(c)	.16	.028	.77	18
Crossing	-	-	-	0 (>45°)
8	.155	.3	.62	153
9	.14	.07	.39	20
10	.14	.15	.39	43
11	.15	.12	.77	73
12	.155	.15	.77	95
Total				768 Volts

Table 4(W) LFI Levels

The 768 volts developed is an end to end LFI longitudinal voltage. That is, the manner in which it is presented will depend on what earth connections are made to the pipeline.

This pipeline section has 8 grading rings, or earth features distributed over the first kilometre from the river crossing, ie within about 500m of the Darra West HV Sub Station. Four of these grading rings were measured for resistance to earth, and the results are given in Appendix 2, Reference 3. As stated in that reference, the ground structure is quite uniform and therefore the resistances are similarly uniform. This means that the eight earths will add (reciprocally) to a net earth resistance of approximately one ohm . The centre of effect will be at the mid point of these eight electrodes, ie about half a kilometre from the river, and adjacent to the Darra West Sub

Station. Two of the earths are in fact only about a dozen metres from the Sub Station wire fence which is bonded to the Sub Station earth.

There are no earth features over approximately 1800m from the last grading ring, to the Wacol end of the pipeline. This means that 500m from the river end of the line is firmly electrically 'anchored' to earth by the electrodes discussed above. As a result, the substantive part of the 768 volts (estimated at 700V) will appear at the Wacol end of the pipeline to ground. Further, this will be via the near zero resistance pipeline, albeit with some reactance, and with a one ohm base resistance. In consequence under a zero sequence HV fault on either of the EHT transmission lines, a serious hazardous voltage will appear on the Wacol end of the line.

The Cathodic Protection (CP) system at Wacol Station Road has an anode resistance of some three ohms plus, but the LFI voltage appears in series with the CP Anode/Cathode circuit. This would almost certainly destroy the CP rectifier, either by the inverse voltage generated (around 1000V peak) or by the forward current (over 100 amps, allowing for reactance in the pipeline). Even the CP wiring could not be expected to withstand these conditions. If the rectifier, remarkably, did withstand the condition, then its protection would be expected to operate and the full LFI voltage would be present at valve spindles or other accessible points at Wacol.

The River Hills end of the pipeline, being anchored to earth by its grading rings would have very little LFI voltage present. Some circulating current of the order of 8 or 10 amps would flow in loop earth circuit from one electrode to the next. A substantial current of the order of 120 amps would flow from the collective earth electrode group to the CP system, until the latter was either destroyed or its protection operated. Following this, the longitudinal voltage would (until the QEC protection operated) be presented as an open circuit voltage with no current flow to Wacol. (A small amount would flow through the pipeline product across the isolating joint at Wacol, but this is of little consequence).

This ends the LFI study proper for the Wacol exposure. Attention is drawn to the "Discussion" below as to suggested ways to overcome the unacceptable LFI voltage condition, and also to the matter of quite serious EPR conditions at Darra West Sub Station.

Discussion:

The disposition of the grading rings in this section indicates that there has been some confusion between the different mechanisms of LFI and EPR.

LFI is a longitudinal induction on the pipeline itself, caused by the flow of phase to earth fault currents in a parallel path. There is no relevant voltage induced in the earth itself. The circuit is that of a gigantic air core transformer.

EPR is a change of potential in the ground, due to the entry or exit of fault current on: tower earths; from fallen conductors; or at the Sub Station(s) whence the fault current returns. There is no effect on an (insulated, ie coated) pipeline.

Grading rings are a (partial) Faraday cage whereby the ground potential is approximately linked to the pipeline, to allow operators to work on the line, or operate valves and the like, enveloped in a like-potential zone, within the grading ring. This is good practice. However, with LFI, the effect is over the whole line. If earths are added at one end only, the other end becomes the terminal of an efficient, and in this case, hazardous, transformer.

Grading rings, if properly designed, are an excellent, if not perfect, protection against EPR conditions - near EHT towers and the like. They are a reasonable protection from LFI conditions also, remembering now that the pipeline itself is the source of hazardous voltage.

The matter of grading ring design should take into account that the electric field is three dimensional. A surface ring will not exert much effect if current flow, essentially at right angles to the electric field is deep, and is deflected under and over a well coated pipeline (EPR). Likewise if the pipeline is dispersing energy (LFI), the current flow path from a fitting, eg valve spindle, will not necessarily be obviated by a shallow ring, as clearly the current path to the earth will be downwards, ie into the earth within the ring as well as without.

In the specific case of the LFI voltage hazard at the Wacol end, the solution fortunately is relatively simple. Further the cost would hardly be prohibitive. As the pipeline has some inductance (though very little resistance) the voltage at the Wacol end can be reduced remarkably and adequately by causing substantial current to flow along the full length of the pipeline.

If a permanent and durable earth electrode is installed at Wacol, the result would be as follows. Assume Reactance (R_L) Appendix 2, Reference 5 is about 5 ohms for the 1.8km circuit path.

The current flow for 700 Volts would be:

$$I = \frac{E\ (\text{voltage})}{Z\ (\text{impedance})}\ \text{amps}$$

$$= \frac{700}{\sqrt{(R_1 + R_2)^2 + (R_L)^2}}\ \text{amps}$$

Where $R_1 + R_2$ are the end earth resistances
R_1 being 1 ohm (Study above)

$$= \frac{700}{\sqrt{(1 + R_2)^2 + 25}}$$

For	R_2 = 1 ohm	I = 129 Amp
	R_2 = 2 ohm	I = 120 Amp
	R_2 = 3 ohm	I = 101 Amp

In each case, the voltage developed across this resistance would be: (E = IR)

$E_1 = 129 \times 1 = 129$ Volts
$E_2 = 120 \times 2 = 240$ Volts
$E_3 = 101 \times 3 = 303$ Volts

As the River Crossing end has a collective resistance to earth of about 1 ohm, the most uniform presentation of potential would be for this proposed electrode to be one ohm - each end of the pipeline would thus rise to 129 volts for a (worst case) fault episode.

It might now be recalled that a Lightning Arc fault current of 5.3kA was used in calculations. Should a nearly impossible fault occur - (structural steel hurled into the conductors by a cyclone for example) the one ohm termination would experience a voltage of -

$$129 \times \frac{7.8}{5.3} = 190 \text{ Volts (current, 190 Amps)}$$

(7.8 from Table 1(W), 5.3 being the rounded fault current for Lightning Arc faults)

This extreme condition is considered acceptable when viewed against AS3859 - The Effect of current through the Human Body. As the 110kV (7.8kA fault level) protection operate time is 150 mSec, the maximum voltage to avoid cardiac fibrillation is 300 Volts, hand to hand or hand to feet.

It is emphasised that there is no Australian Standard on pipeline LFI and EPR conditions, and the constraint in referencing AS3859 could well be considered excessively severe.

Thus the recommendation, positively, is to install a one ohm electrode at Wacol (Recommendation 1), capable of carrying 200 amps for a short period, eg 300 mSec. The effect on the CP System would appear trifling. In fact, for something less than one amp, the earthing electrode would also be protected from corrosion. The capacity of the CP rectifier is more than adequate for this purpose. No polarisation cell should be fitted to the earth electrode.

The matter of EPR has been referred to in the text above.

There are several cardinal rules in EPR co-ordination. The primary one is **Never install an access or earth facility to a pipe, cable, or duct within the EPR zone of an electricity HV Sub Station** (Recommendation 2). The two grading rings at Darra West Sub Station infringe this rule completely. The problem is that while the grading rings may or may not protect an operator within their ambit, the grading ring itself picks up high currents, impressed at high voltage and transmits this energy to the pipe, cable or duct.

In the case of the pipeline, this electrical condition is then faithfully transmitted to all other access points via its excellent conductive path. It is only partially mitigated by the several other earth features on the pipeline. As all earth faults on all transmission systems return current to the Sub Station, there will be many occurrences of EPR at that point.

In addition, if an LFI situation exists on the pipeline, the EPR condition is added to it, if there are adjacent, ie coupling, earth features.

No EPR calculations have been made, but the "point-blank" siting of the two adjacent grading rings appears totally unacceptable. It would seem imperative to remove these earth features, and if valve access is vital to replace the mechanical link with an insulating material, eg seasoned hardwood or other substance of like performance. Safe work practices also should be adopted near any HV Sub Stations, especially in thunderstorms. This at least would include insulated footwear and rubber gloves.

In Summary, the Recommendations listed at the beginning of this study are emphasised as necessary.

As cable sized to grading rings and earth electrodes are apparently all 35mm - not all were inspected - the current carrying capacity would be adequate.

Appendix 1

Written References pertinent to Induction Studies and Earth Potential Rise Calculations; also relevant formulae and their derivation.

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1. "Application Guide for the Low Frequency Induction Code" by the Central Joint Committee for the Co-ordination of Power and Telecommunications Systems. 1981.

2. Code of Practice for the Protection of Personnel and Equipment against Earth Potential Rise caused by High Voltage Power System Faults - same origin as (1) above. 1984.

3. Australian Standard AS2832.1 - Guide to the Protection of Metals, Pipes, Cables and Ducts.

4. Resistivity of copper at 20°C. is 1.72×10^{-8} ohm/metre (from A.E. Knowlton, Electrical Engineers Handbook Section 4).

5. E = CILK. This is the traditional induction formula, from Reference 1, Page 8. It will be found in many other texts.

E	=	The induced longitudinal voltage between the ends of the exposure.
C	=	The mutual impedance per length of exposure, without shielding, at 50Hz.
I	=	The inducing (zero sequence in this case) current.
L	=	Length of exposure (possibly Cosine θ if the paths are not parallel).
K	=	The shielding factor ($0<K<1$) due to the presence of modifying conduction.

C is a complex quantity and is expanded to:

$$C = 2\pi f \left[\log_e \left(1 + \frac{6 \times 10^5 \rho}{d^2\ f}\right)\right] \times 10^{-4} \text{ henries/km}$$

f is frequency (50Hz)
ρ is soil resistivity in ohm.metres
d is spacing in metres between earth return circuits.

There are other derivations possible. However it is customary to utilise a nomogram (eg Reference 1 Page 19) to derive C.

6. $d = \frac{I\rho}{2\pi V}$ or $V = \frac{I\rho}{2\pi d}$

This is the traditional formula to indicate the relationship between resistivity (p), Current (I), Voltage (V) at distance (d) from a current injection point into uniform soil. It will be found in AS2832.1, Reference 3, and other Standards.

7. The resistivity for mild steel is 14×10^{-8} ohm/metre (from A.E. Knowlton, Electrical Engineers Handbook Section 4).

Appendix 2

Data Calculated, Recorded or Provided on Request by Officers of Wilson Walton International, also Zero Sequence Fault Current Levels provided by QEC - Specific to this Job.

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1. Resistance of Pipe wall. 1670mm dia x 12mm wall thickness, using 14×10^{-8} ohm metre, ex Appendix1, Reference 7. R = .0002 ohms/km.

2. Resistance of Earth features on pipeline, measured 3 terminal mode on Geohm or Evershed DET 2/2 tester.

   - from Anstead End to River

			Ohms
(i)	Grading Ring at Valve Station		3.5
(ii)	Air Valve	12/19	7.5
(iii)	Scour	11/58	8
(iv)	Air Valve	12/20	8
(v)	Earth Electrode		1.8
(vi)	Scour	11/59	3.4
(vii)	Air Valve	12/21	5.2
(viii)	Scour	11/60	3.4
(ix)	Air Valve	12/22	6.5
(x)	Scour	11/61	4
(xi)	Air Valve	12/23	5.2
(xii)	Scour	11/62	2.1
(xiii)	Air Valve	12/24	2.8
(xiv)	Scour	11/63	1.8
(xv)	Air Valve	12/25	1.9
(xvi)	Scour	11/64	2.1
(xvii)	Air Valve	12/26	2.3
(xviii)	Scour	11/65	2.2
(xix)	Earth Electrode		.8
(xx)	Air Valve	12/27	6
(xxi)	Scour	11/66	6.6

3. Resistance of Earth Features on pipeline, measured as in (2) above.

   - from River Crossing to Wacol

Note: An apparent pipeline design change on the Wacol side of the river has resulted in grading rings only being installed on the first few scour pipes and air valves at the River Hills end of the Section. After the pipeline departs from the QEC easement, no such earthing/unipotential facilities exist. Consequently, because of the uniformity of the terrain, geologically, and also in view of the results of the deep resistivity tests (See 4 below), it was decided that only four measurements were warranted of the 800m (approximately) section and two in between. This comprises 50% of the eight earth features.

The four readings were:

1.	At Insulating Joint (Wacol Side) adjacent to River Crossing	(Grading Ring)	7.4 ohms
2.	In Summers Road Opposite Darra West Sub Station	(Grading Ring)	5.8 ohms
3.	Behind River Hills, approximately 400m from 1 above	(Grading Ring)	6.8 ohms
4.	Near Wolston Creek approximately 800m from 1 above	(Last Grading Ring)	7.2 ohms

Attention is drawn to "Discussion" on this disposition, in the body of the Study.

4. Four Terminal Resistivity Measurements along the pipeline route. The six sets of tests are respectively at or near each end, and at the mid point of each of the two sections or either side of the river. An Evershed and Vignoles DET 2/2 Test Set was used.

Site	Pin Spacing	Meter Reading ohms	Calculated Resistivity ohm/metres
At Anstead End	20m 10m 4m	0.318 0.428 1.004	40 27 25
In QEC Easement from Pinjarra Road to Lather Road (near midpoint of longest direct exposure)	20m 10m 4m	0.07 0.094 0.135	8.8 5.9 3.4
At River End of Anstead Section on high ground before pipeline descends to crossing	20m 10m 4m	0.335 1.05 1.45	42 66 36
At River End of Wacol Section	20m 10m 4m	0.152 0.308 1.42	19 19 36
At Entrance to Wacol Correctional Centre Property - River or Western side	20m 10m 4m	0.21 0.556 1.2	26 35 30
In Wacol Correctional Centre, near Wacol Station Road	20m 10m 4m	0.315 0.482 1.094	40 30 28

5. DC and AC current measurements at Cathodic Protection Rectifier Site at Pipeline Crossing of Wacol Station Road.

DC Measurement:

7V at 1.6A = 5 ohms (R_1)

Polarity Reversed

5.4V at 2.55A = 2.1 ohms (R_2)

The cathodic protection polarisation is clearly visible.

Taking a Mean $\sqrt{R_1.R_2}$ = 3.2 ohms (R) **(1)**

This is the equivalent unpolarised resistance of the earth at the test site.

AC Measurement:

2.3V at 0.3A = 7.7 ohms (Z) **(2)**

Inasmuch as the DC resistance of the pipe wall is negligible (Cl.7.App.1), the increase in impedance is due to the pipe reactance. The length of pipe will however be quite imprecise because of the proliferation of earth features on the pipeline. In any case it cannot be greater than the route from the test site to the river (2800m), where an isolation joint exists. Even though there would be a path through the pipeline product at this point, this path would be of the order of 20 ohms or greater, which as a first approximation can be ignored.

Extracting the 50Hz reactive component from these -

$$R = \sqrt{Z^2 - R^2}$$

$$= \sqrt{7.7^2 - 3.2^2}$$

$$= \sqrt{49.05}$$

$$= 7 \text{ ohms}$$

Thus the reactive component at 50Hz of the pipeline for a distance not exceeding 2.8km is 7 ohms. The confidence placed in this figure is ± 25%, due to the uncertainty of the return earth path locations.

The centre of the group of earth conducting grading rings is approximately 2.2km distant. The two pipeline insulating joints - one at Wacol and one at the river crossing will shunt about 20 ohms each, it is considered that the pipeline reactance, at 50Hz, may be taken as **3 ohms/kilometre.**

It would be a profitable exercise to conduct measurements at some future time on a newly installed (say 1km) pipeline, before any cathodic protection is applied and before any earthing facilities are connected, to ascertain the order of reactance to be expected for future designs.

6. Zero Sequence (Phase to Earth) calculations made by QEC, supplied by telephone by Mr F. Tuting of that organisation.

NOTE:

(i) Fault currents will vary significantly depending on location. As QEC operates a mesh system, the amount contributed to a given point will comprise the sum of several paths. However, for LFI calculations, only the fault current returning to the source Sub Station along the exposure section(s) is relevant.

Further, the fault mechanism will cause variations. A conductor falling to earth (uncommon fault type) will experience some resistance (usually taken as 10 ohms, conservatively). This will result in less current than a fault involving tower or Overhead Earth Wire contact, but will exert a higher level of induction per ampere than will a fault partially carried by the OHEW.

(ii) The QEC advises that the protection trip time is 100 mS for the 275kV line and 150 mS for the 100kV.

(iii) The QEC further advises that Darra West (at River Hills) Sub Station has mesh links from several directions on the 110kV network. It therefore has a relatively high busbar (station earth) fault level. It has no transformers and the 275kV feeder bypasses it.

(iv) The shielding factor for both overhead earth wires is given as .77

Stated Fault Levels

110kV	West Darra Sub Station busbar of which 2.7kA is from Ashgrove West and **7.8kA** is from Rocklea	**17.27kA**
	Mt. Crosby Road (Anstead) of which **9.24kA** is from West Darra and 3.64 from Ashgrove West	**12.88kA**
	Wacol Station Road 6.64kA from West Darra plus a component unspecified from Rocklea (not required)	
275kV	**At Moggill Road** (Anstead) of which 6.72kA is from Karana Sub Station and 2.34 from Rocklea Sub Station	**9.1kA**
	At West Darra of which 6.36 is from Karana and 2.46 from Rocklea.	**8.81kA**

The shielding factor on both OHEW served lines is quoted as **0.77.**

The **maximum** current possible per exposure is therefore:

Wacol (to River)	7.8kA from the 110kV feeder
Anstead (to River)	9.24kA from the 110kV feeder

These figures do not take account of fault types.