CMM

CONSTRUCTION
MATERIALS
MANAGEMENT

3 Dukeswood
Chestfield
Whitstable
Kent CT5 3PJ
England

Telephone: 01227 794442
Fax: 01227 794443
International
Telephone: +44 1227 794442
Fax: +44 1227 794443
E-Mail: cmm-asterisk@dial.pipex.com

SUBJECT: **IN-SITU COMPRESSIVE STRENGTH TESTING OF PRECAST CONCRETE TUNNEL LINING SEGMENTS USING CAPO TEST**

CLIENT: **TRANSLINK JOINT VENTURE ISLE OF GRAIN**

REFERENCE: **IST0041090-1**

DATE: **2nd NOVEMBER 1990**

CONTENTS

References:

Draft British Standard 1881 : Part 207 - Recommendations for the Assessment of Concrete Strength by Near-to-Surface Tests.

British Standard 6089 : 1981 - Assessment of Concrete in Existing Structures.

RILEM Workshop Report March 1990 : - Testing During Construction - In-Place testing for Quality Assurance and early loading operations with pullout testing and maturity measurements.

A M Neville - Properties of Concrete.

PART I

SCOPE

This report describes briefly the LOK and CAPO test and discusses in detail the testing exercise carried out on precast concrete tunnel lining segments and counterpart specimens for correlation. The purpose of this exercise being to gain approval for the use of CAPO test to determine in-situ compressive strength in cases of non compliance.

PART II

INTRODUCTION

An in-situ concrete compressive strength testing service giving rapid but reliable results has been offered to TML by Construction Materials Management.

The service is based on the LOK and CAPO pull-out test system.

An immediate use for this service has been identified at the Isle of Grain Precast yard as a means of testing tunnel lining segments which have been referred from the production process for problems associated with the concrete. A rapid confirmation of concrete strength in this situation could greatly speed up the decision making associated with non-conformance and whether replacement segments would be required to be manufactured. This service would be equally applicable to testing of in-situ concrete and shotcrete in the tunnel, or concrete structures at the Cheriton Terminal site.

It was arranged that engineering personnel from TML attend Imperial College for a 1 day lecture/demonstration of the LOK and CAPO test system given by the manufacturer. In addition site trials at TML were organised in order to evaluate the test method and correlate the results of CAPO tests carried out on concrete segments and corresponding test specimens.

Brief details only of the test method, its history and application are given in this report as more complete background information has already been submitted to TML.

PART III

SUMMARY

1. GENERAL

Brief details of the LOK and CAPO TEST system are given in Part IV.

The CAPO TEST exercise on TML Precast Concrete Tunnel Lining Segments and counterpart test specimens is reported in Part V.

2. THE LOK AND CAPO TEST SYSTEM

A versatile method of testing for compressive strength of in-situ concrete and capable of providing the results rapidly.

3. CAPO TEST CORRELATION EXERCISE

An exercise to correlate CAPO test results with compressive strength results was carried out for TML at Grain. In order to evaluate the test data it was necessary to consider the effect of differing maturity in the test pieces. The CAPO test results together with the corresponding strength information are discussed in Part V.

4. CONCLUSION

Good correlation was found between CAPO test results and production cured compressive strength, the criteria on which the TML precast concrete strength specification is based.

Signed:......................

Date: 9th November 1990

PART IV

THE LOK TEST AND CAPO TEST SYSTEM

1. GENERAL

This section gives a brief insight into the LOK TEST and CAPO TEST system.

The LOK TEST and CAPO TEST have been designed to provide compressive strength information about the concrete that actually exists in a structure or structural element. The tests, therefore, take into account the effects of placing, compaction, protection and curing of the concrete. In contrast, standard cube or cylinder testing only provides the potential strength of the concrete. Site cured test specimens are sometimes used to indicate strength in a structure but because of temperature differences are unlikely to be truly representative unless a full scale temperature/maturity calibration has been undertaken.

2. TESTING THE COVER ZONE

Furthermore the LOK TEST and CAPO TEST are performed in the surface layer of concrete which in the majority of structural applications is the most critical region, being the protecting 'overcoat' or cover to the reinforcing steel. If defects such as a porous surface, thermal or shrinkage cracking are present then the pullout forces will decrease thus indicating potentially low resistance to chloride ingress, moisture movement, and carbonation.

3. LOK AND CAPO TEST v CORING

When investigating in-situ compressive strength by cutting and testing cores the surface layer is almost always discarded before the compression test, thus the result obtained represents the inner portion only.

The risk of weakening a structural element by coring is now eliminated.

The CAPO TEST can be safely carried out on the segments in both the horizontal or vertical plane, thus minimizing the need for extra handling.

4. REPAIR AFTER TEST

A further advantage of these tests is that they only leave a small cone shaped hole in the surface layer which can be easily repaired. The hole left after core cutting would be approximately 65 times larger than that remaining after LOK or CAPO testing.

5. INSTANT RESULTS

The failure load recorded on the LOK or CAPO test pull machine is readily converted into compressive strength therefore the time between carrying out the test and the result being available is a matter of minutes.

Conventional coring and testing takes a minimum of 4 days, but the norm is probably 14 days or longer.

6. THE LOK TEST

This test is used where inserts can be positioned in fresh concrete by either fixing to the formwork or floating in the top surface. The LOK test is used to determine whether the in-situ concrete has reached adequate strength before removal of formwork or application of post-tensioning. Where fast track construction, e.g. high rise building is employed the LOK test can be used to optimise formwork usage.

7. THE CAPO TEST

Literally, the cut and pull out test, it is used where an in-situ determination of compressive strength is required in hardened concrete. e.g. structural evaluation, fire damage, etc.

After marking the positioning of the reinforcing steel, a small diameter hole is drilled and then under reamed. A pull bolt is inserted and expanded to form a disc. The counterpressure device is placed in position. Diagrams showing the stages are shown at Appendix A.

8. THE LOK AND CAPO COMPRESSION TEST

The next stage of carrying out the compression test applies to both tests. The hand operated hydraulic pull machine is connected either to the LOK insert or to the CAPO pull bolt. The pull force is applied and the peak load shown on the dial gauge at failure is recorded. The compressive strength is derived from the peak load and the calibration data.

Although, for the purposes of TML Grain, only the CAPO test for hardened concrete is of interest, the LOK test has been mentioned because much of the literature on pull out testing refers to LOK TEST. Apart from the different methods of placing the steel insert disc the 2 tests are virtually synonomous.

9. THE FAILURE MECHANISM

The stages of tensile cracking followed by compression then shear/ tensile forces as the steel disc is pulled towards the counterpressure are best explained by C.G. Petersen in the RILEM Workshop Report March 1990.

10. LOK/CAPO TEST BACKGROUND

This test system has been in use for the past 20 years. It has been employed extensively in Canada and the United States of America and its use is recognised by ASTM C-900.

It has also been used successfully in the Middle East and many European countries; in particular Norway, Sweden, Denmark, the Netherlands and Luxembourg. Swedish, Danish and Dutch Standards that cover its use are in existence.

In Great Britain the tests have been used to a limited extent in the past and some sets of equipment are held by U.K. companies. Wider use of the method is expected now that BS 1881: Part 207 - Recommendations for the assessment of concrete strength by near-to-surface tests, exists as a draft standard and is expected to emerge in its final form during 1991.

BS 6089: 1981 - Assessment of concrete in existing structures recognises this generic form of testing.

Widespread use is being made of LOK and CAPO test on the Storebaelt Project in Denmark for quality control testing with procedures firmly fixed into the Quality Assurance systems for both the Tunnel and Western Bridge contracts.

PART V

CAPO TESTING OF PRECAST CONCRETE SEGMENTS

1. GENERAL

On 23rd/24th October 1990 a series of CAPO tests were carried out on precast concrete tunnel lining segments at the Isle of Grain. CAPO tests were also carried out on test specimens cast at the same time as the segments. Test specimens had also been cast so that corresponding cubes (compressive) and cylinder (tensile) strengths could be provided both standard and production (steam) cured. 3 pairs of segments had been cast to give ages at test of 4, 7 and 28 days.

In addition cubes at 154 and 329 days were provided.

The position of the reinforcing steel was marked on all test segments.

2. CAPO TEST ON PRECAST SEGMENTS

4 determinations of the CAPO test were performed in the top half of each segment. The top portion was chosen in order that the concrete should be from the same batch as the test specimen s. (R36 segments require 2 batches of concrete). The majority of tests were carried out on the intrados but with some on the extrados.

A table of results for the concrete is shown at Appendix B and for the CAPO testing at Appendix C.

It will be noticed that the 4 day old segments are stronger than the 7 day ones, this is due largely to difference in workability. The trend is borne out by both the CAPO test and the cube strengths.

3. CAPO TEST ON TEST SPECIMENS

In order to attempt additional correlations the CAPO test was also carried out on corresponding laboratory standard cured and production (steam) cured 150mm cubes and 300 x 150mm cylinders.

It must be emphasised that the CAPO test should not normally be carried out within 100mm distance from edges and corners. In order to support the edges, the cubes were clamped back into their moulds and a steel band was tightened around the top of the cylinders. The incidence of radial cracking was likely to be higher than normally experienced during this exercise because of the high strengths involved.

After the CAPO test the specimens were examined carefully for radial cracking which could have affected the result. The results are shown in the table at Appendix C. Any result affected by radial cracking has been marked and discounted.

The CAPO tests on the production cured cubes provided consistent results but cracking was noted on some of the standard cured cubes making correlation difficult. Because of the reduced surface area of the tops of the cylinders the incidence of cracking was higher.

4. LABORATORY STRENGTH TESTS

While the CAPO tests were being performed, pairs of standard and production cubes and cylinders were being tested for compressive and indirect tensile strength respectively.

The table of laboratory strength tests is shown at Appendix B.

The compressive strength results are also included alongside the CAPO test results for comparison purposes in the table at Appendix C.

5. CONCRETE MATURITY CALCULATIONS

Because of their different temperature history, the strength of the precast segments, the corresponding standard cured and production cured test specimens will all have achieved different strengths by the time of test. In order to make comparisons it is necessary to convert all values to the same standard, in this case by calculating the concrete maturity (or the equivalent strengths that would have been achieved if all items had remained at $20^{o}C$).

From temperature monitoring work and computer prediction studies carried out during early production at the Isle of Grain and knowing the ambient temperatures of the area where the test segments were stored it has been possible to make these calculations.

An additional factor that should be pointed out is the generally accepted phenomenon that there is some loss in compressive strength when heat curing is used to accelerate the strength gain. In this case, it means that the production cured test specimens and the precast segments will show slightly lower strengths than the standard cured specimens of equivalent maturity. The explanation is based on the retarding effect of heat on the products of hydration in the cement paste after the rapid initial acceleration. Various explanations can be found in the literature, one such reference is A.M. Neville - Properties of Concrete - Influence of Temperature on Strength of Concrete.

A graph showing temperature relationship of the surface of an R36 segment during production and storage together with production cured and standard cured cubes is included at Appendix D. It can be seen from the graph that temperature of the production cured cubes and the surface of the segments are the same almost until they emerge from the curing tunnel. (A very useful feature when considering strength for lifting purposes when demoulding.)

The following table shows the difference in maturity of the test items:

ITEM	AGE days	AGE hours	ACTUAL MATURITY °C hours	EQUIVALENT AGE @ 20°C	
				hours	days
SEGMENT SURFACE	4	96	2320	116	4.83
PRODUCTION CUBES			2130	107	4.46
STANDARD CUBES			1860	93	3.88
SEGMENT SURFACE	7	168	3185	159	6.63
PRODUCTION CUBES			3580	179	7.46
STANDARD CUBES			3295	165	6.88
SEGMENT SURFACE	28	672	9235	462	19.25
PRODUCTION CUBES			13655	683	28.46
STANDARD CUBES			13375	669	27.88
PRODUCTION CUBES	154	3696	74130	3707	154.44
PRODUCTION CUBES	329	7896	158130	7907	329.44

TABLE 1 COMPARISON OF MATURITY OF CONCRETE TEST SPECIMENS

From Table 1 it can be seen that the specimens are of a similar equivalent age at 4 days, with the segment surface slightly ahead of the production cubes which in turn are slightly further advanced than the standard cubes. At 7 days they are still all close together but the segment surface is now lagging behind the production and the standard cured cubes.

At 28 days the segment surface is now over 9 days behind the production cubes, thus highlighting the need for strength correction.

6. COMPRESSIVE STRENGTH CORRECTION

Strength development curves for standard and production cured cubes (150mm) are included at Appendix E.

Where the maturity of one item is significantly different from another then the compressive strengths at the equivalent ages can be read from the strength development curve. As only the 28 day old segment surfaces are of a significantly different maturity it is considered that only these require correction.

Since it is the production cured cubes that form the basis of the TML compressive strength specification criteria, then the CAPO TEST results must be calibrated against these.

7. CAPO TEST CALIBRATION

The results shown in Table 2 below are extracted from the full table of results given in Appendix C.

The mean CAPO load for each segment is tabulated against the compressive strength from the corresponding production cube. The CAPO load from the test that was performed on one of the set of production cubes, produced with each segment, is also tabulated against the production cube compressive strength. In addition the CAPO test was performed on two elderly cubes in order to increase the range of correlation.

The results from this table have been used to plot the CAPO load/strength correlation chart - see Appendix F.

As a check to confirm the correlation, the compressive strength has been found from the chart by reading off against CAPO load. This correlation check is recorded in Table 2 below.

SEGMENT CODE	MEAN CAPO LOAD kN	PRODUCTION CUBE STRENGTH N/mm^2	CORRECTED CUBE STRENGTH	CORRELATION CHECK
CAPO TEST ON SEGMENTS				
AR36B46223252	38.2	52.7	--	55
BR36B44523252	35.9	52.1	--	53
CR36B42823222	31.8	47.9	--	47
CR36B46423222	33.5	48.2	--	49
BR36B42722922	43.6	71.0	65	64
DR36B49322922	43.8	72.3	65	64
CAPO TEST ON PRODUCTION CUBES				
AR36B46223252	38.4	52.7	--	55
BR36B44523252	38.5	52.1	--	55
CR36B42823222	33.4	47.9	--	49
CR36B46423222	33.4	48.2	--	49
BR36B42722922	48.6	71.0	--	71
DR36B49322922	48.6	72.3	--	71
154 days	58.8	81.5	--	84
329 days	68.7	96.2	--	97

TABLE 2 CAPO LOAD AND PRODUCTION CUBE STRENGTHS

8. CAPO TEST ON PRODUCTION AND STANDARD CURED CYLINDERS

Only 5 of the 12 CAPO test results obtained from cylinders could be said to be reliable. The unreliable ones were caused by the radial cracking mentioned previously and was particularly evident in the higher strength specimens.

The valid results from the lover strength cylinders, however, did compare favourably with the CAPO tests carried out on their counterpart cubes.

Should this exercise be required in the future, to correlate CAPO test with compressive strength of cylinders on high strength concrete, it would be advisable to use larger diameter test specimens.

9. CAPO TEST ON STANDARD CURED CUBES

Radial cracking affected 3 out of 8 CAPO test results carried out on standard cured cubes. The remaining results generally fitted well into the correlation for standard cured concrete supplied by the maker of CAPO test.

If it were necessary to calibrate CAPO test on TML Precast concrete against standard cured concrete at high strengths, it would be advisable to perform a few more tests in the 70 to 100 N/mm^2 strength range. This would confirm whether standard cured TML Precast concrete behaves as normal concrete or whether it requires unique calibration above 70 N/mm^2. Below 70 the CAPO results are comparable with standard cubes as can be seen from Table 3 below:

SEGMENT CODE	MEAN CAPO LOAD kN	STANDARD CUBE STRENGTH MPa	STRENGTH FROM CAPO CHART
CAPO TEST ON STANDARD CUBES			
AR36B46223252	44.4	59.0	58
BR36B44523252	39.4	52.9	51
CR36B42823222	39.4¢	54.9	51
CR36B46423222	42.4	55.6	54
BR36B42722922	53.6	78.6	72
DR36B49322922	43.4¢	79.7	--
154 days	67.7	93.6	88
329 days	60.8¢	98.9	--
	¢ denotes radial cracking		

TABLE 3 CAPO LOAD AND STANDARD CUBE STRENGTH

PART VI

CONCLUSIONS

1. PAST EXPERIENCE

It is clear from the following sources that the CAPO and LOK TEST system is a well established and useful test method:

Results of research by various technical institutions.

Information provided in several technical papers provided by manufacturer and others.

Experience of use in the field by contractors and consultants.

The acceptance by several national standard institutions.

2. THE TML CAPO TEST EXERCISE

The CAPO test provided good correlation with compressive strength on precast concrete tunnel lining segments as can be seen from the results included in this report.

It is recommended that 3 CAPO test determinations per segment are taken. If variable quality concrete is present to cause a significant difference in the 3 results, then the test is versatile enough for additional tests to be made on the spot.

APPENDIX A

DIAGRAM SHOWING STAGES OF CAPO TEST

STAGES OF CAPO TEST

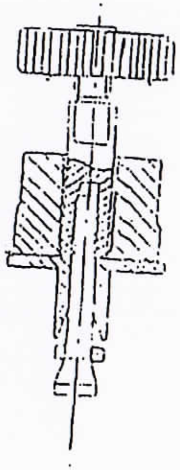


FIG 1
PULL BOLT
ASSEMBLY
READY FOR
INSERTION

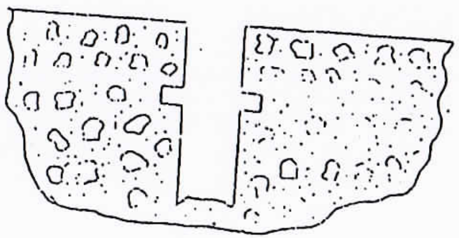


FIG 2
HOLE DRILLED
AND MILLED
(READY FOR TEST)

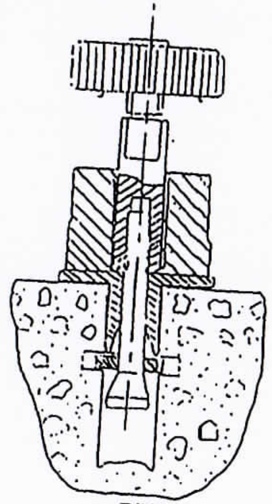


FIG 3
PULL BOLT
IN POSITION
STARTING TO
EXPAND DISC

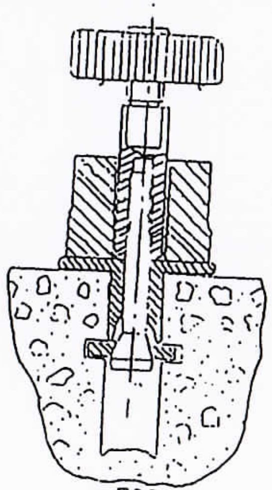


FIG 4
DISC FULLY
EXPANDED
READY FOR
PULL TEST

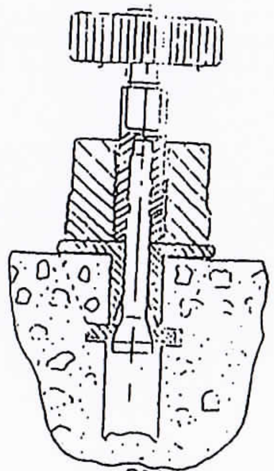


FIG 5
CONE SHAPED
FAILURE ZONE
AS DISC IS
PULLED TOWARDS
COUNTER PRESSURE

APPENDIX B

TABLE OF TEST CONCRETE RESULTS

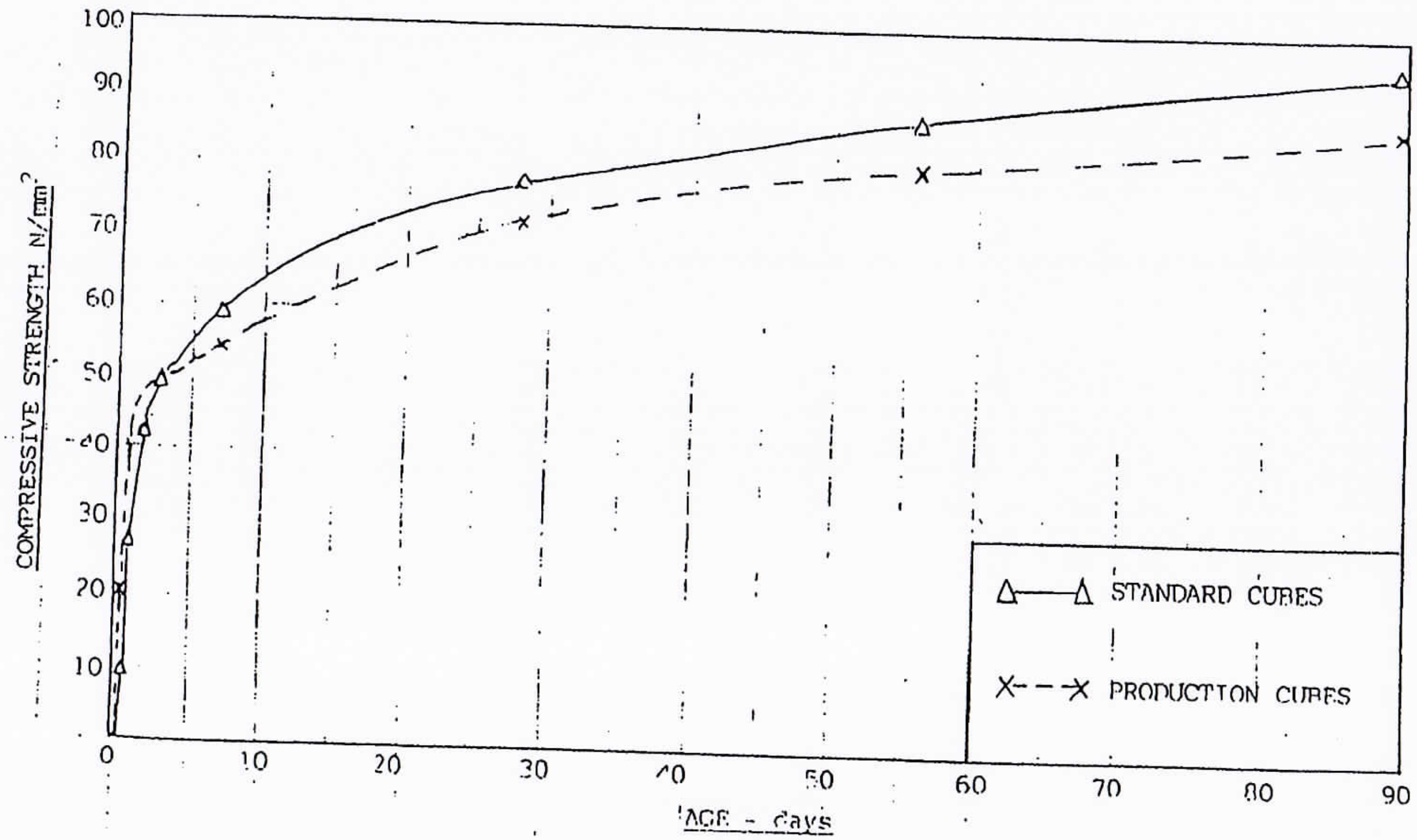
SEGMENT CODE	DATE CAST	TIME CAST	AGE @ TEST days	VEBE secs	CONCRETE TEMP. °C	CURING TUNNEL TEMPERATURES ENTRANCE °C	CENTRE °C	EXIT °C	COMPRESSIVE STRENGTH PRODUCTION CUBES MPa	STANDARD CUBES MPa	TENSILE STRENGTH PRODUCTION CYLINDERS MPa	STANDARD CYLINDERS MPa
AR36B46223252	19-10-90	1105	4	8	25	48	59	54	54.2 51.1 (52.7)	59.7 58.2 (59.0)	1.9 1.8 (1.9)	2.7 3.6 (3.2)
BR36B44523252	19-10-90	1045	4	5	25	48	59	54	53.1 51.1 (52.1)	52.8 53.0 (52.9)	3.0 2.2 (2.6)	2.2 2.1 (2.2)
CR36B42823222	16-10-90	1100	7	7	24	48	59	55	46.5 49.2 (47.9)	55.5 54.2 (54.9)	2.5 2.7 (2.6)	3.2 3.3 (3.3)
CR36B46423222	16-10-90	1125	7	7	25	48	59	55	47.1 49.2 (48.2)	55.7 55.5 (55.6)	2.9 2.3 (2.6)	3.6 3.7 (3.7)
BR36B12722922	25-10-90	1105	28	9	22	51	58	51	71.1 70.9 (71.0)	77.6 79.5 (78.6)	5.2 4.8 (5.0)	5.5 4.4 (5.0)
DR36B49322922	25-10-90	1155	28	11	22	51	58	51	70.4 74.1 (72.3)	78.6 80.7 (79.7)	3.9 4.4 (4.2)	4.5 5.2 (4.9)

NOTES:
i) Tensile strengths are from cylinder splitting tests on 300x150mm specimens.
ii) Compressive strengths are from 150mm cubes.
iii) ( ) Indicates mean of 2 individual results.

TABLE SHOWING PROPERTIES OF CONCRETE TO BE CAPO TESTED

APPENDIX C

TABLE OF CAPO TEST RESULTS



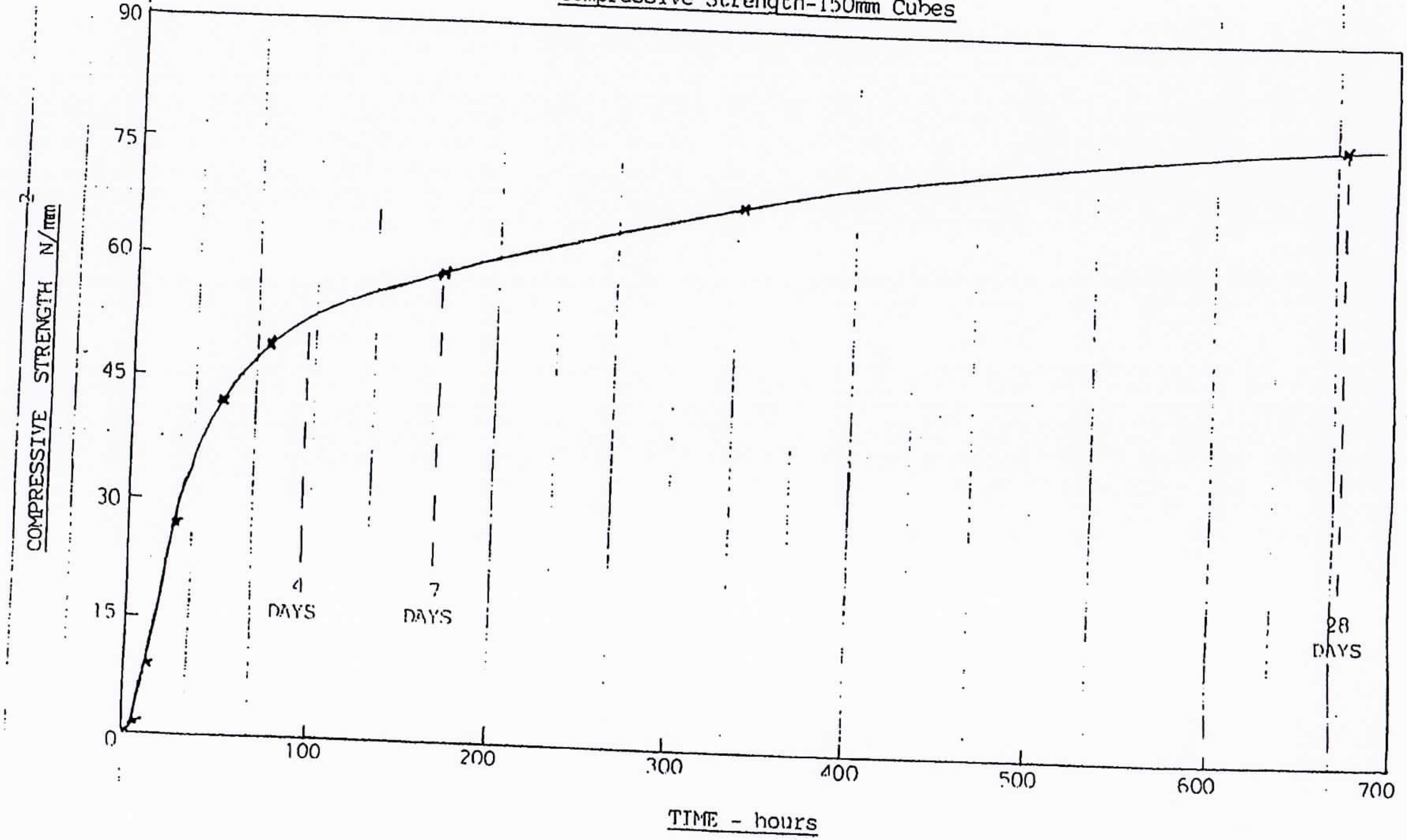
TML PRECAST SEGMENT CONCRETE

STRENGTH DEVELOPMENT - STANDARD AND PRODUCTION CUBES (150mm)

TML PRECAST SEGMENT CONCRETE

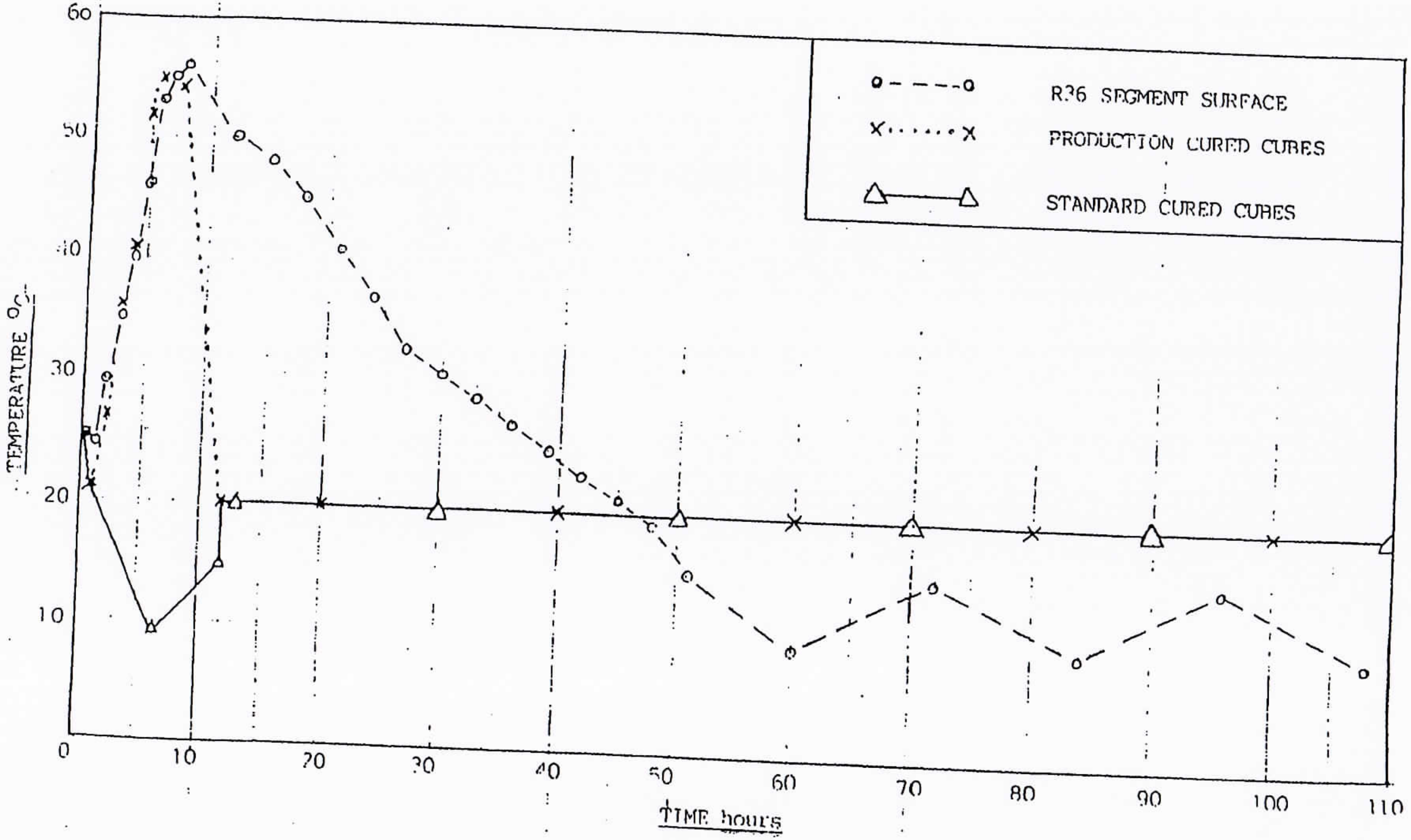
STRENGTH DEVELOPMENT @ 20 °C

Compressive Strength-150mm Cubes



APPENDIX D

TEMPERATURE/TIME GRAPH



TML PRECAST SEGMENT CONCRETE - TEMPERATURE/TIME RELATIONSHIP

APPENDIX E

STRENGTH DEVELOPMENT CURVES

i) Standard and Production Cubes.

ii) Standard Cubes Showing Early Development.

APPENDIX F

LOAD/STRENGTH CORRELATION CHART

PRECAST CONCRETE SEGMENTS

CAPO TEST RESULTS

SEGMENT CODE	AGE days	CAPO TEST DETERMINATIONS: PRECAST CONCRETE TUNNEL SEGMENTS				PRODUCTION CUBES		PRODUCTION CYLINDERS		STANDARD CUBES		STANDARD CYLINDERS		COMPRESSIVE STRENGTH 150mm CUBES: PRODUCTION CURED CUBE STRENGTH MPa	STANDARD CURED CUBE STRENGTH MPa
		TEST POSITION	CAPO DIAL kN	CAPO LOAD kN	MEAN LOAD kN	CAPO DIAL kN	CAPO LOAD kN	CAPO DIAL kN	CAPO LOAD kN	CAPO DIAL kN	CAPO LOAD kN	CAPO DIAL kN	CAPO LOAD kN		
AR35B46223252	4	1 Top Int	38.0	38.4	38.7	38.0	38.4	37.5	37.9	44.0	44.4	44.0	44.4	51.1	58.2
		2 Top Int	34.5	34.9										54.2	59.7
		3 Top Ext	35.5	35.9										(52.7)	(59.0)
		4 Top Ext	43.0	43.4											
BR36B44523252	4	1 Top Int	35.5	35.9	35.9	38.5	38.9	39.0	39.4	39.0	39.4	35.5	35.9¢	51.1	53.0
		2 Top Int	•32.5	32.9										53.1	52.8
		3 Top Ext	35.5	35.9										(52.1)	(52.9)
		4 Top Ext	•32.0	32.4											
CR36B42823222	7	1 Top Int	32.0	32.4	31.8	33.0	33.4	28.0	28.4¢	39.0	39.4¢	39.0	39.4	46.5	54.2
		2 Top Int	30.5	30.9										49.2	55.5
		3 Top Int	32.0	32.4										(47.9)	(54.9)
		4 Top Int	31.0	31.4											
CR36B46423222	7	1 Top Int	33.0	33.4	33.5	33.0	33.4	38.0	38.4	42.0	42.4	33.0	33.4¢	47.1	55.5
		2 Top Int	31.5	31.9										49.7	55.7
		3 Top Int	38.0	38.4										(48.2)	(55.6)
		4 Top Int	30.0	30.4											
SR36B42722922	28	1 Top Int	48.0	48.6	43.6	48.0	48.6	40.0	40.4¢	53.0	53.6	45.5	45.9¢	70.9	77.6
		2 Top Int	41.5	41.9										71.1	79.5
		3 Top Int	40.5	40.9										(71.0)	(78.6)
		4 Top Int	43.5	43.9											
		5 Top Int	42.5	42.9											
DR36B49322922	28	1 Top Int	47.0	42.4	43.8	48.0	48.6	39.0	39.4¢	43.0	43.4¢	40+	40+	74.1	80.7
		2 Top Int	41.0	41.4										70.4	78.6
		3 Top Int	46.5	47.0										(72.3)	(79.7)
		4 Top Int	44.0	44.4											
CUBES ONLY	154	BASE	-	-	-	58.0	58.8	-	-	67.0	67.7	-	-	81.5	93.6
	329	BASE	-	-	-	68.0	68.7	-	-	60.0	60.8¢	-	-	96.2	98.9

DATE OF TEST: 23rd October 1990

INSTRUMENT NO: 13 - 2075

Int = Intrados of segment

Ext = Extrados of segment

( ) = Mean of 2 results

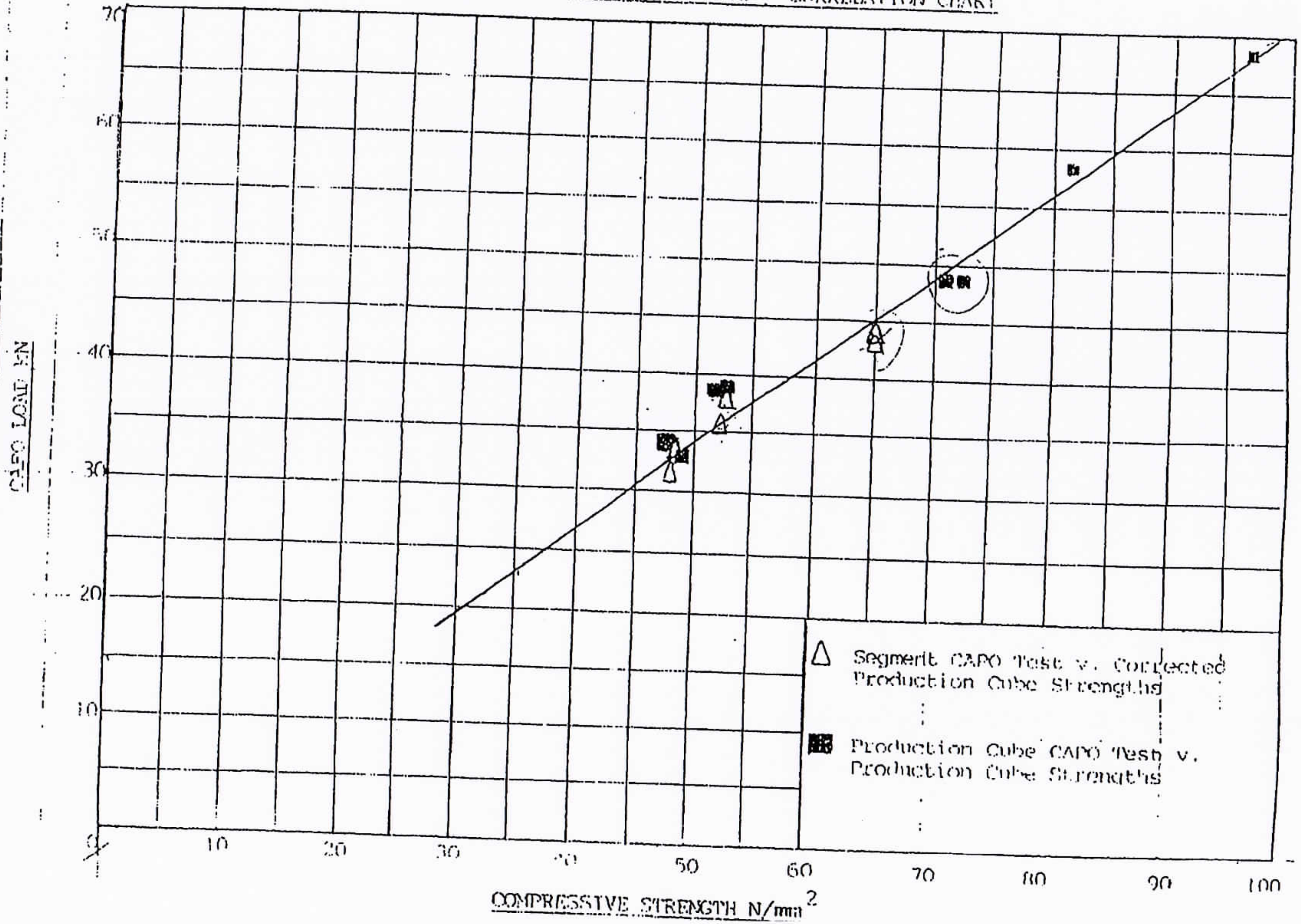
• = Test result affected by blowholes

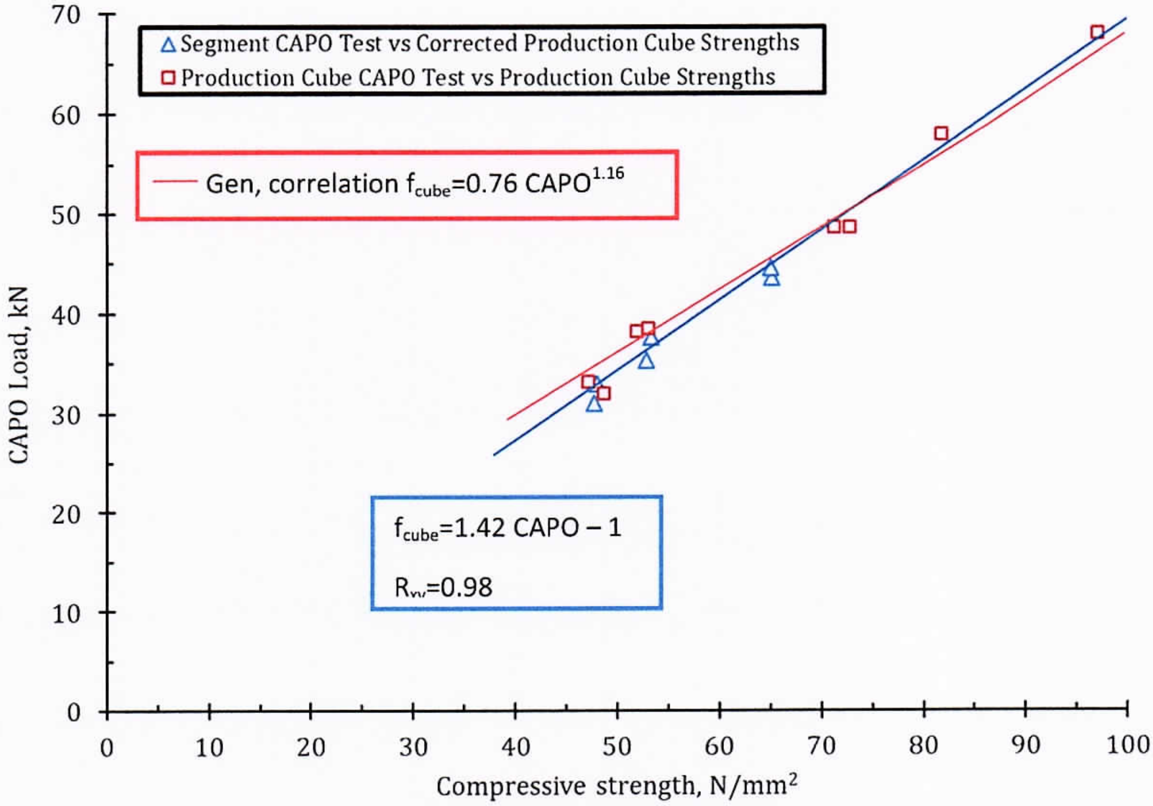
¢ = Test result affected by cracking/edge effect

· = Test loaded twice

CMM Construction Materials Management

TML PRECAST SEGMENT CONCRETE - CORRELATION CHART




Segment CAPO Test vs Corrected Production Cube Strengths
Production Cube CAPO Test vs Production Cube Strengths
Gen, correlation f_{cube}=0.76 CAPO$^{1.16}$
f_{cube}=1.42 CAPO – 1
R_{vv}=0.98
CAPO Load, kN
0
10
20
30
40
50
60
70
0
10
20
30
40
50
60
70
80
90
100
Compressive strength, N/mm^2