THE BONDING OF NEW TO OLD CONCRETE BRIDGE DECKS AS AFFECTED BY VEHICULAR TRAFFIC

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EXECUTIVE SUMMARY

This project, undertaken in 1992, simulated the situation when a bridge is widened with a new concrete extension and then, after a delay period, traffic continues to use the existing old concrete bridge while the extension is curing. Traffic effects were simulated by repeated vertical displacements of "old" concrete, connected by starter bars to "new" concrete which is not displaced. The effects of these displacements and of a range of delay times on the bond between the "old" and "new" concrete during curing were then quantified.

A series of test specimens of "old" and "new" reinforced concrete was prepared, in 1992, by casting the "new" concrete against the "old" concrete, with two reinforcing starter bars connecting the two. Two 12 mm diameter starter bars projected 174 mm from the "old" concrete into the "new" concrete.

Thirteen specimens were prepared and tested. The first was a control sample which was not subjected to any differential displacement. Of the remaining 12 specimens, two tests were undertaken at each of three delay times and two differential displacements, giving a total of six combinations of the two variables. The specimens were subjected to differential displacements of either 1 mm or 2 mm and recovery for 800 cycles over 2 hours, and the delay times were 8½ hours, 16 hours and 24 hours.

After the displacement sequence all specimens were stored and cured until the "new" concrete reached an age of 28 days. The "old" and "new" concrete specimens were then pulled apart and the maximum loads achieved during this process were recorded.

The limited testing carried out indicated that the strength of the joint was greater than the yield strength of the starter bars at all delay times except in the case of 8½ hours delay and of 2 mm differential displacement.

The scatter of results was too great to allow definitive curves to be produced that related bond strength to delay times. However, the project results give a rough guide to practical delay times that can be used in construction applications before the passage of traffic is allowed. These results apply to cases of pure shear deformation between old and new concrete, and do not allow for variations in temperature.

ABSTRACT

This project, undertaken in 1992, simulated the situation when a bridge is widened with a new concrete extension and then, after a delay period, traffic continues to use the existing old concrete bridge while the extension is curing. Traffic effects were simulated by repeated vertical displacements of "old" concrete, connected by starter bars to "new" concrete which is not displaced. The effects of these displacements and of a range of delay times on the bond between the "old" and "new" concrete during curing were then quantified.

After 28 days curing, the "old" and "new" concrete specimens were pulled apart and the maximum loads achieved during this process were recorded. The project results give a rough guide to practical delay times that can be used in construction applications before the passage of traffic is allowed. These results apply to cases of pure shear deformation between old and new concrete, and do not allow for variations in temperature.

1. INTRODUCTION

Economic factors are now causing engineers to consider widening existing bridges in preference to replacing the complete bridge. Widening is often achieved by casting a reinforced concrete extension or precast beam element with infill concrete deck slabs that are cast in situ.

Usually the traffic flow cannot be interrupted for any length of time because no alternative routes are available. The continuing passage of heavy vehicles on the existing bridge deck while the extension is curing will cause deflections of the existing bridge deck. The new deck slab is not subjected to the same deflections and therefore differential movement is expected to occur between the two parts.

The effect of the deflections of the old concrete on the bond between the old and new reinforced concrete caused by traffic during the curing period is of concern for designers and construction personnel.

The transfer of forces between the old concrete and the new concrete is achieved by providing shear reinforcement connecting the old and new parts. A critical aspect of such design, when considering earliest use of the structure after widening, is the bond strength between the reinforcing bars and the new concrete (to avoid pullout of the bars which have been epoxied into the old concrete).

While the new section of bridge is generally self supporting from pier to pier, differential movement between the new and old structures will lead to degradation of the joint, allowing the ingress of water and deleterious materials. These materials can force the old and new structures apart and corrode the reinforcing steel. It is therefore important to ensure that the old and new concrete will behave as a single entity.

During 1988 a literature survey was undertaken by Central Laboratories for the then National Roads Board (now Transit New Zealand) (Central Laboratories Report 88-B5401) to determine the results of previous investigative work that examined the effect of differential displacement on the bond between old and new reinforced concrete during curing.

The literature survey highlighted that, while many investigators had studied the effect of vibration on the new concrete mass and the bond between fresh concrete and contained reinforcing steel, little work had been done to address the effects of differential displacements on the bond between the stationary new concrete and the old concrete while it continues to be trafficked.

As a result, the study now reported was commenced in 1992 to quantify the effect of differential displacement during curing on the bond between old and new reinforced concrete by deriving curves relating bond strength of the joint to the delay time before differential movement was allowed to occur. This would provide designers with quantitative guidance on acceptable delay times to allow in bridge widening projects.

2. TEST DESIGN

In bridge widening projects, short reinforcing bars called starter bars are epoxied into the edge of the existing bridge, and reinforcing in the new structure is lapped on to these.

To obtain quantitative information on the bond between the old and new reinforced concrete, a test procedure was designed to measure the load which would cause the starter bars to pull out of new concrete (pullout tests). The distance that these starter bars should extend into the new concrete first had to be determined. To produce curves relating bond strength to delay time after pouring the new concrete and before displacement commenced, the failure mechanism needed to be one of bar pullout rather than one of bar failure.

Much work has been undertaken to determine the bond strength between reinforcing steel and concrete (see reference list contained in Chapter 9 of Park and Paulay (1975)). Current New Zealand design code requirements are empirical relationships based on a multitude of studies. Clause 5.3.7.2 of the New Zealand Concrete Code NZS 3101:1982 (SANZ 1982) has a number of equations for the determination of the development length of reinforcing bars depending on the bar size and bar spacing. For a deformed 12 mm diameter reinforcing bar, D12, the development length can be taken as 24 times the bar diameter (24 x 12 mm = 288 mm) or, when considering the concrete strength and bar spacing, the development length, l_{db}, is given by:

$$l_{db} = \frac{380\ A_b}{c\sqrt{f'_c}}$$

where A_b = cross-section area of the bar (mm^2)
f'_c = concrete compressive strength (N/mm^2)
c = factor relating to bar spacing and cover, not greater than three bar diameters (mm)

For a D12 bar in concrete of 30 MPa compressive strength:

$$l_{db} = \frac{380 \times 113}{3 \times 12 \times \sqrt{30}} = 218 \text{ mm}$$

In this test series the bars extended 174 mm into the "new"[1] concrete, 80% of the minimum code development length.

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[1] "New", "old" - apply to the test specimens: New, old - apply to bridge decks.

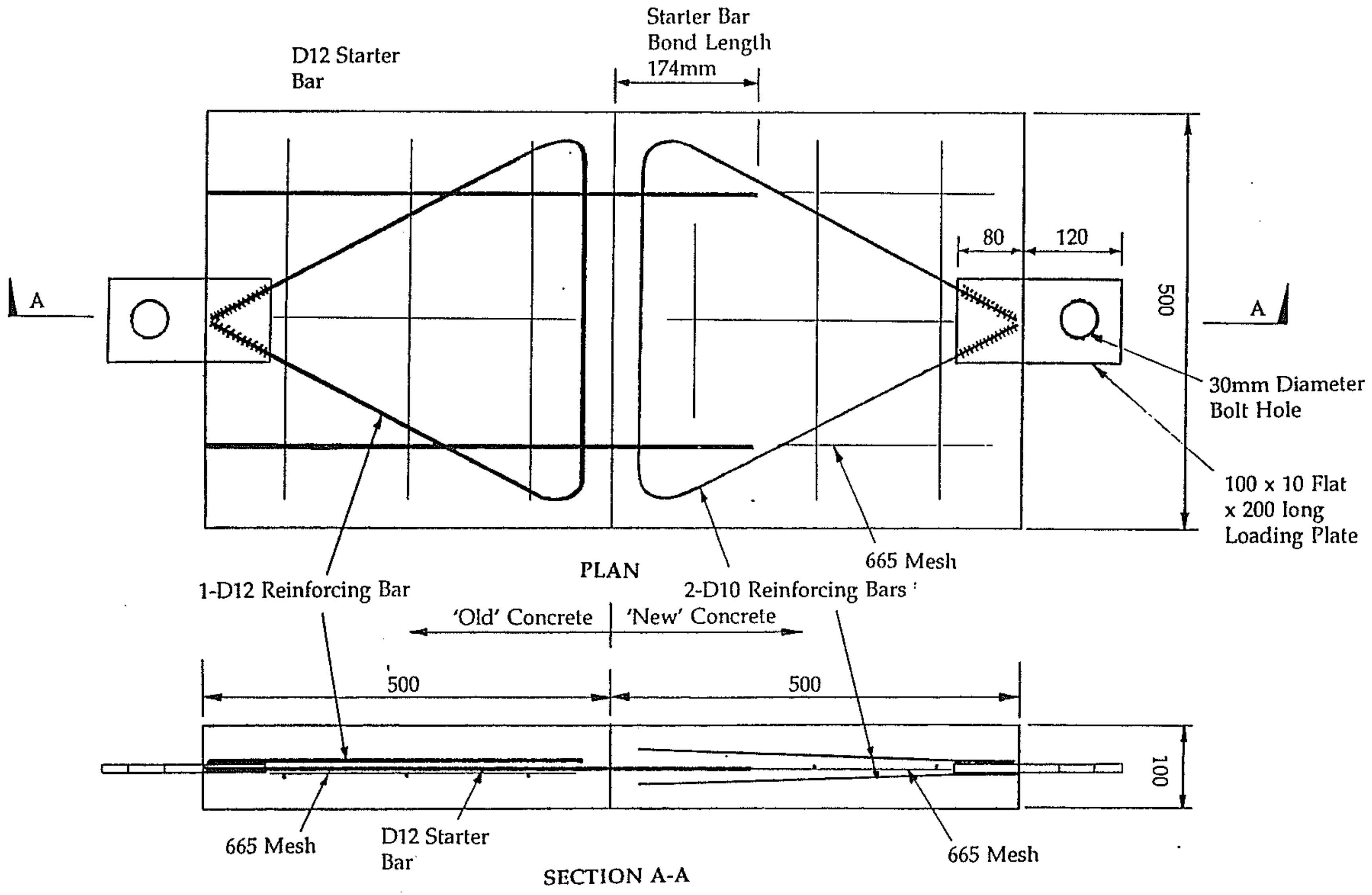


Figure 1. Details of the test specimens (dimensions in mm).

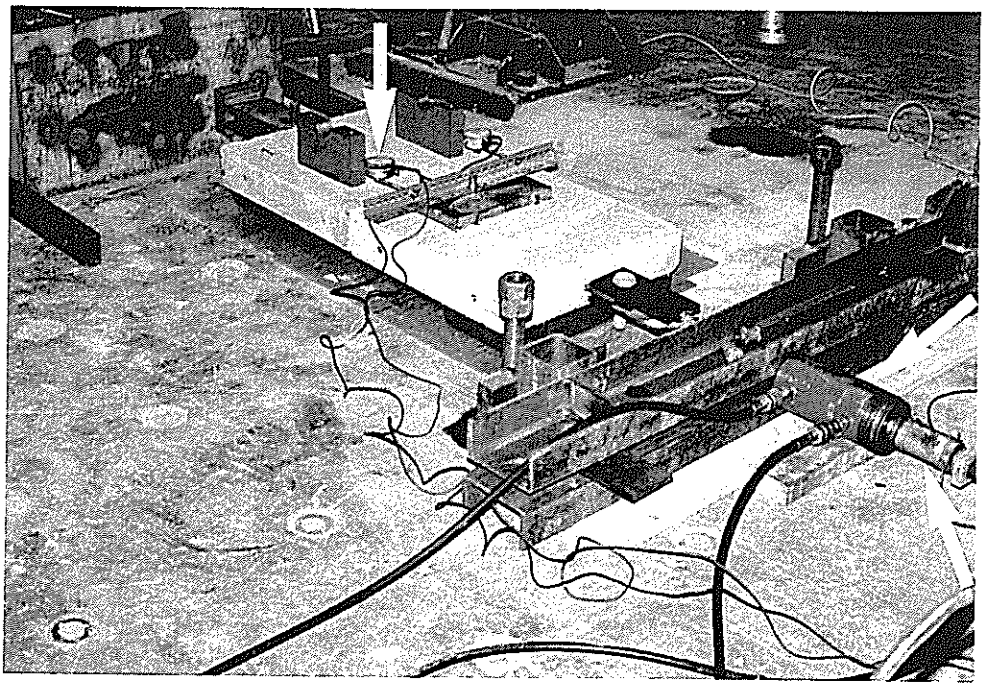
Details of the test specimens are given in Figure 1. A total of 13 specimens was constructed. Of the "old" half, 13 copies were constructed (as in Figure 1) and the D12 starter bars were trimmed to give a projected length of 174 mm. Concrete for these was supplied as ready mixed concrete. The specified compressive strength of the concrete was 30 Mpa.

Tensile testing was also undertaken on two samples of D12 reinforcing steel to obtain the yield load and the failure (ultimate) load.

To simulate the passage of traffic during the curing phase, a test rig (Figure 2) was built utilising the laboratory's servo controlled actuator, which allowed the "old" concrete section to deflect downwards and return to its original position, while the "new" concrete remained fixed in position (Figure 2). This represented the case of pure shear deformation between the "old" and the "new" concrete. The test rig was constructed in such a way that allowed the second ("new") half of the specimen to be poured in it, and therefore no movement between the "old" and "new" concrete occurred before the commencement of the cycling. The small quantities of concrete required precluded supply from a ready mixed plant, and so each half specimen was batched in the laboratory using a bowl mixer. The mix was batched by weight with the aim of producing consistent compressive strengths between the specimens of approximately 24 MPa after 28 days.

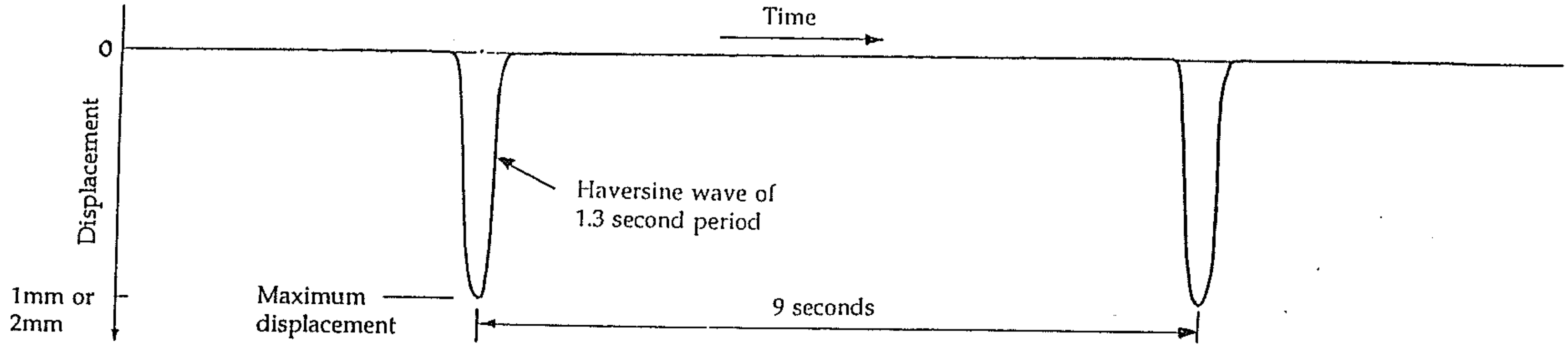
Figure 2. Test rig for pulling the "old" concrete apart from the "new" concrete.

Displacement measuring dial guage

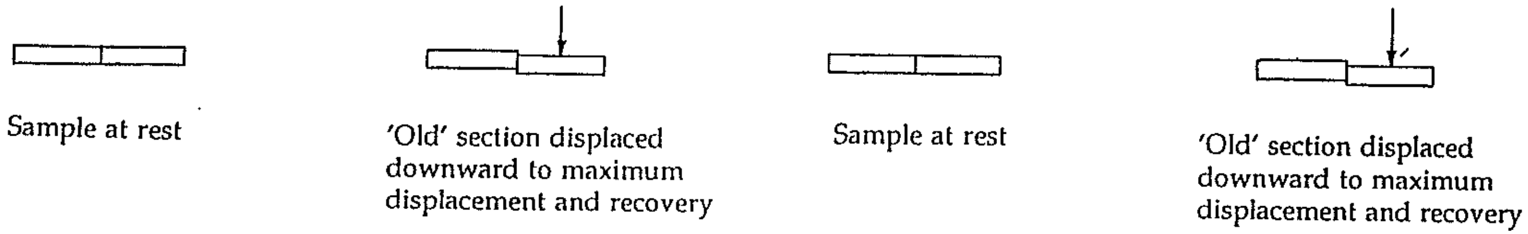


Ram

Loadcell



Graphical presentation of displacement of specimens vs time (2 cycles shown)



Pictorial view of sample displacement with time

Note:
1 Samples were displaced a total of 800 times over a 2 hour period.
2 Maximum displacement levels were either 1mm or 2mm.

Figure 3. Pattern of displacement cycles to which the test specimens were subjected, against time.

The air temperature at the time of casting and curing was not recorded. However it was estimated to be in the range of 3 °C as all concrete was mixed, poured and cured in the laboratory test hall where the fluctuation in temperature over the test period was no more than 3 °C.

The time history of the repeated deflection applied to the samples is shown in Figure 3. The 9 second delay between cycles was chosen to allow some recovery to occur in the concrete, as would be expected in practice. A 2-hour period of cycling was used which resulted in 800 deflection cycles. This was considered to be probably greater than the number of deflections experienced on a typical structure during the curing period of new concrete.

Deflection levels of 1 mm and 2 mm were chosen as being representative of bridge span deflections that would typically occur under heavy vehicles. Levels that approximated these were recorded during recent bridge monitoring studies (Jacks and Beattie 1992)

Three delay periods between casting and the commencement of the deflection cycling were selected. These were 8 hours, 16 hours and 24 hours. The first was selected to represent a bridge being reopened to traffic at the end of a day in which the extension was poured early in the morning. The second represented an overnight delay between pouring and reopening, and the third modelled a one day delay between pouring and re-opening. By the time the 8-hour period had elapsed, final set had occurred in the "new" concrete.

On completion of the cycling, each specimen was removed from the test rig to storage for a period of 28 days from the pour date of the "new" concrete. Then the "old" and "new" halves of the specimens were pulled apart to measure the 28-day bond strength of the two D12 starter bars.

3. RESULTS

Only 13 samples could be built in the time allowed for the project. The first of the 13 was a control sample on which no displacement cycling was carried out. As previously mentioned, the two variables considered were the delay time to the commencement of cycling, and the amplitude of the deflection. Two specimens were constructed for each combination of the three delay times and the two deflection amplitudes.

3.1 Delay Time

As the actuator had malfunctioned and had prevented a start to cycling of the first specimen after 8 hours, the planned 8 hour delay time was extended to 8½ hours for the test series.

3.2 Tensile Tests on Reinforcement

Tensile tests were undertaken on two samples of the D12 bars in a Universal test machine to determine the yield load and the ultimate failure load of the bars. The mean yield stress was found to be 329 MPa and the failure stress to be 467 MPa. Because two starter bars were used in the test specimens, the expected yield load was calculated to be:

$$329 \text{ MPa} \times 2 \times 113 \text{ mm}^2 \times 10^{-3} = 74 \text{ kN}$$

and the ultimate failure load was calculated to be:

$$467 \text{ MPa} \times 2 \times 113 \text{ mm}^2 \times 10^{-3} = 105 \text{ kN}$$

3.3 Compressive Strength of Concrete

Concrete compressive strength test results are presented in Table 1. Cylinders for these tests were cast at the same time as the specimen was poured. Cylinders were not taken from each pour for testing as the same mix proportions were used each time, and the curing conditions were similar.

Table 1. Results of concrete compression tests.

Specimen No.	Age at Test (Days)	Compressive Strength (MPa)
All [2]	8	26.0
2	28	23.0
4	29	24.5
5	28	27.0
8	29	27.5
11	28	27.5
13	30	26.0

[2] "Old" half of all specimens - all poured at the same time.

At the time that cycling began, the "old" concrete was a minimum of 8 days old for all specimens.

3.4 Pullout Tests

Results from the 13 pullout tests are summarised in Table 2.

Table 2. Summary of results for the pullout tests.

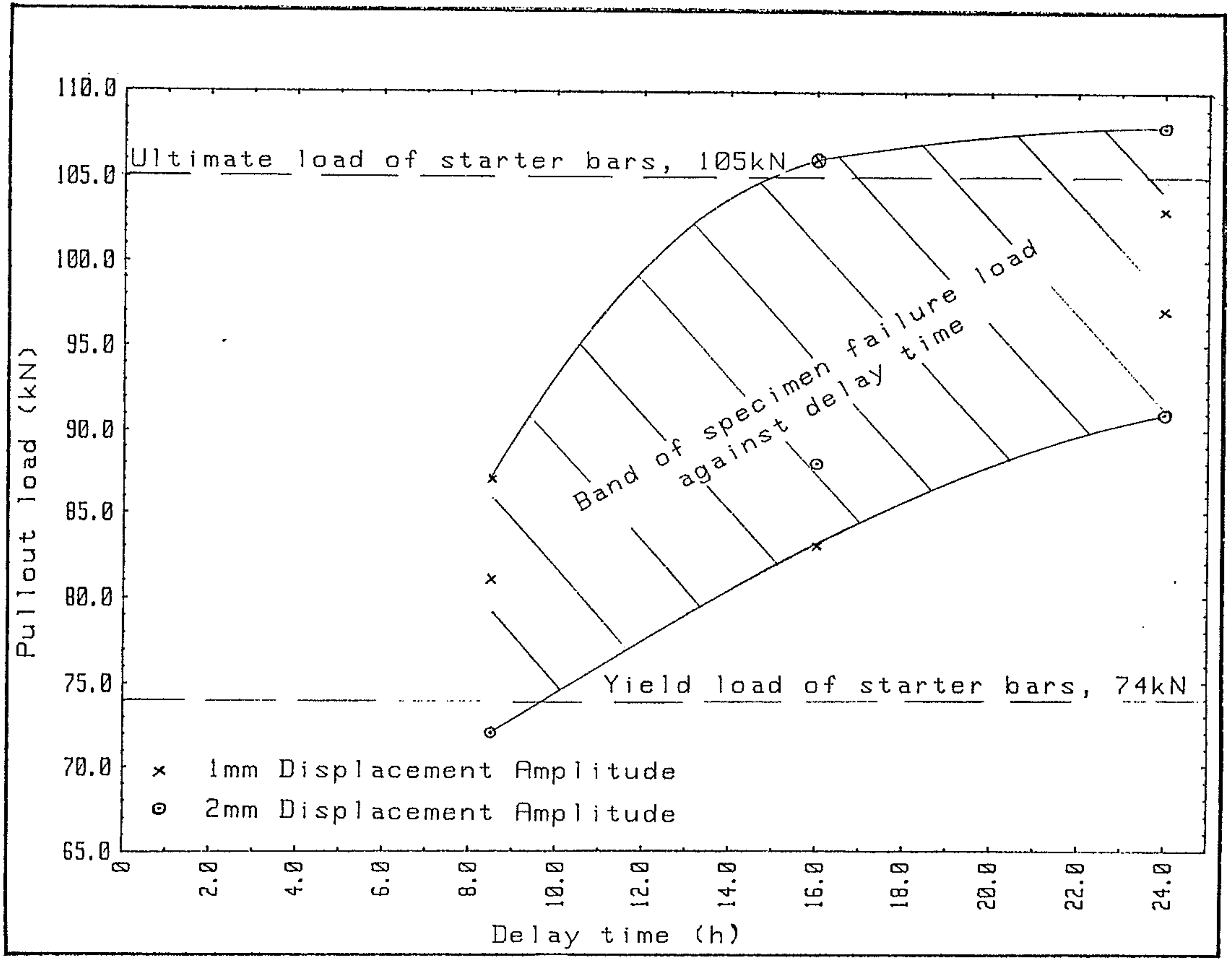
Specimen No.	Delay before Cycling (h)	No. of Cycles	Displacement (mm)	Peak Load [3] (kN)	Failure Mechanism
1	No cycling (control)	-	-	86	Pullout of bars
2	8.5	800	1.0	87	Pullout of bars
3	16.0	800	1.0	83	Pullout of bars
4	24.0	485 [4]	1.0	97	Pullout of bars
5	8.5	801	2.0	72	Pullout of bars
6	16.0	800	2.0	88	Pullout of bars
7	24.0	800	2.0	91	Pullout of bars
8	8.5	800	1.0	81	Pullout of bars
9	16.0	800	1.0	106	Pullout of bars
10	24.0	800	1.0	103	Pullout of bars
11	8.5	800	2.0	29	Pullout of bars
12	16.0	800	2.0	106	Pullout of bars
13	24.0	800	2.0	108	Pullout of bars

[3] Peak load was defined as the highest load reached in the test.

[4] Test machine shut down due to overheating.

As can be seen from Table 2, the peak loads achieved were greater than the calculated yield load (see p. 14) for the two D12 bars, except in two cases (No. 5, 11). Inspection of the load–displacement plots also revealed a change in slope of the plots, excluding specimens 5 and 11, at or around 74 kN, indicating that yielding is actually occurring.

Figure 4. Pullout load v delay time to start of displacement cycling.



With specimens 5 and 11, cycling commenced 8½ hours after pouring and the displacement amplitude was 2 mm. In both cases no sudden failure was observed, as happened with the other specimens, indicating that the early cycling and high displacement amplitude had prevented the concrete from bonding to the starter bars.

An attempt has been made to plot the results (Figure 4) to determine trends, but the scatter is too great to allow any definite curves to be plotted. If the results, excluding specimen 11, are fitted within a band, a trend towards a lower pullout load can be seen as the delay time reduces from 24 hours to 8½ hours. If cycling had begun earlier than 8½ hours after pouring, the pullout load may have been less than the yield load had the trend continued.

4. CONCLUSIONS

Although curves that relate bond strength to delay time before differential movement is allowed could not be derived, the results achieved in the project are very encouraging. Thus displacements of the old structure expected after 8½ hours from pouring will apparently cause no harm to the bond between the new concrete and the reinforcing bars. In this test series the starter bars were deliberately made shorter than those specified in the NZS 3101:1982 concrete code (SANZ 1982), so that a pullout mode of failure would be forced to occur before a bar failure. Despite this, the bars were still stressed to beyond their yield load before pullout occurred.

Tests were not conducted to determine the influence of differential displacement during the setting phase (first 8 hours). The test results that were obtained suggest that lower pullout loads might be expected during the setting phase.

This project used a limited number of experimental tests to give a rough guide to practical delay times that can be used in construction applications, before the passage of traffic is allowed. The limited nature of the project should be recognised however, and in particular:

- A study of the physical mechanisms involved in the deterioration of the bar bond was not required. This limited any extension of the project findings. Further research may obtain this information for pure shear loading by using a model which can be structurally analysed.

  Such a model could fix a length of the reinforcing bar, not allowing any rotations, to represent being held in the old concrete. The stiffness of the curing concrete could be modelled by attaching springs at right angles along the length of the bar set in curing concrete. Stiffness properties of the concrete would be required for such an analysis.

- Only the case of pure shear deformation between old and new concrete was considered. In practice, cases will occur where rotations/moments cause the bars to be loaded in tension. These may be more critical loading cases and could be the subject of further research.

- Variations of concrete maturity with temperature at the time of cyclic loading were not considered.

5. RECOMMENDATION

From the results of the project it is recommended that consideration is given to extending the work to cover:

- The case where rotations of the joint between old and new concrete cause the bond bars to be loaded in tension.

- Variations in concrete maturity with temperature.

6. REFERENCES

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