Onsite Hardness Testing of Reinforcement

***Andrew Sonnenberg and Geoff Boully**: VicRoads Design*

SYNOPSIS

Onsite hardness testing and laboratory based tensile testing was conducted on reinforcement used in pre 1960 bridges. The primary purpose of the testing was to develop a procedure to determine the yield strength of reinforcement insitu using a non destructive test method to improve the estimation of the load carrying capacity of existing bridges. The secondary objective was to collect data on the yield strength of reinforcement to assist in predicting the benefits which may be obtained from onsite hardness testing of bridges.

From the test data collected a correlation between the onsite hardness and the yield strength of reinforcement was determined. This empirical correlation may be used to assess onsite the yield strength of reinforcement. The average yield strength of reinforcement tested was found to be approximately 30% higher than the manufactures specifications. The results of the tensile testing indicated that assuming a yield strength of 230 MPa is conservative for unidentified reinforcement and that characteristic strengths of up to 285 MPa are possible in pre 1960 bridges.

1 BACKGROUND

VicRoads manages many older concrete bridges which were designed to carry loads less than is currently allowed. The actual load carrying capacity of these bridges may be significantly higher than their design capacity. One reason for the higher load carrying capacity is that the material properties such as reinforcement yield strength may be considerably better than conservative design values based on the manufactures minimum specifications.

For reinforced concrete bridges the strength of the steel reinforcement has a significant impact on the load capacity. When designing a bridge the strength of the reinforcement is determined from the relevant Australian Code. The current codes used are the 1996 Australian Bridge Design Code (1) and the steel reinforcing materials standard AS/NZS 4671 (2). The code specifies the minimum yield strength of reinforcement.

There have been a number of grades of reinforcement available over the past 100 years and the minimum yield strength of that reinforcement varies. For assessment of existing bridges an assumed value of 230 MPa for the yield strength of reinforcement is conservative. If the reinforcement can be inspected and the type of bar identified then it may be possible to assume an increased yield strength. For instance if an inspection shows that the bars used in a bridge are twisted square bars then a minimum yield strength of 410 MPa may be used.

Typically the steel used in the pre 1960 bridges was plain round bar and these type of bars have been the main focus of this investigation.

As the steel reinforcement in existing bridges has been made to meet a minimum yield strength, the actual yield strength will generally be higher. From the current investigation it was found that in some bridges the reinforcement was over 50 MPa higher than the minimum specified value. For a minimum yield strength of 230 MPa this represents a 22% increase in strength. If a non destructive method can be found to determine the actual yield strength of reinforcement in existing bridges this may allow a bridge to remain in service without the Authority and user costs associated with applying load limits, strengthening or replacing the structure.

The principal objective was to develop a procedure to determine the yield strength of reinforcement in existing bridges using an insitu test method. The procedure can then be used on bridges where the yield strength of the reinforcement is unknown. Currently if the strength of a reinforced bridge is to be assessed and the reinforcement yield strength is unknown a conservative design value of about 230 MPa is generally assumed.

Over the past three years reinforcement was extracted from demolished sections of pre 1960 bridges. The reinforcement was tested onsite for its hardness and then removed and tested for chemical, mechanical and hardness properties in the laboratory.

2 ONSITE HARDNESS TESTING

Two onsite hardness testers were investigated, the Equotip hardness tester and the Microdur portable hardness tester.

2.1 Equotip hardness tester

The Equotip hardness testers gives a LD reading which is then converted to Vickers hardness. The machine is based on a rebound test as opposed to the Vickers test which uses indentation. In a report to VicRoads by Opus International Consultants (3) it was recommended that the Equotip hardness tester was suitable for bar diameters of 16 mm and greater. Subsequent discussions with Opus and the current investigations by VicRoads suggest that the Equotip tester is suitable for bar sizes 19 mm and greater.

Opus states that they have successfully tested 19mm bars with the Equotip hardness tester. They have had no success with 12mm and 16 mm bars. There are two possible reasons for this. The first reason is that the smaller bars are inherently unstable due to their small size - the Equotip tester relies on a rigid substrate. The second reason was that the flat which is ground on the bar for testing tends to be relatively narrow for a small diameter bar so the risks of poor and variable alignment of the test head is increased.

Opus international consultants have successfully used the Equotip hardness tester in New Zealand to correlate yield strength and ultimate strength.

2.2 Microdur hardness tester

The Microdur hardness tester gives results directly in terms of Vickers hardness. When used on 9 specimens obtained from the Helendite Road bridge the results were found to be variable (approximately 10% variation between largest and smallest reading for the repeat tests on the same specimen). This variability may be due to the test equipment or the small impact force. The machine uses a 9.8N impact force. This force is insufficient to test further than the surface of the specimen, as the indentation it makes on the surface is small.

2.3 Preferred onsite hardness tester

The Equotip was selected as the preferred on site hardness tester for the works due to recommendations by Opus. The following test procedure provided by Opus was used for the investigations.

Step 1. Select bars to be tested in straight section of reinforcing where the steel is unlikely to have been cold worked, eg bends, welds.

Step 2. Remove cover concrete from the bars to be tested over a length of approximately 150 mm using a diamond saw and pneumatic hammer. Refer to Figure 1. Concrete should be removed so that a maximum of half the diameter of the bar is exposed. If more than this is exposed the bar may be unsuitable for testing.

Figure 1: Concrete cover removed from U-slab leg

Step 3. Preparation of the bar requires a flat to be ground on the bar wide enough to support the Equotip probe (about 10 mm) and 80 to 100 mm long. The surface must be ground to a degree that provides a flat surface with no grinding marks and almost polished in appearance. Use of a linishing tool or power file has been found to give the best results using 60 grit paper for initial preparation followed by finishing with a 120 or 180 grit paper. Refer to Figure 2.

Figure 2: Flat ground on bar

Step 4. On each bar to be tested carry out five impact "readings" (L values). Average the five readings to give a "test result" for the bar. Where the range of hardness readings within a particular test results exceed 15 then the test procedure should be critically reassessed. It is likely that the test surface has not been prepared adequately. Refer to Figure 3.

Figure 3: Hardness test machine in use

Step 5. The minimum recommended spacing between impact points is 3mm. Closer spacing than this may cause erroneous results. Misleading results may also be caused by locating the impact point too close to the edge of the prepared area or a defect. Each test should be inspected before the result is recorded as representative.

Step 6. The Equotip tester is calibrated for vertical impact directions. For other impact directions the measured hardness value L must be corrected in accordance with the manufactures specifications. The correction values must be subtracted from the L-values. The corrected L-values should then be converted to equivalent Vickers hardness using the manufactures tables. The conversion assumes an elastic modulus for the steel of 210,000 MPa.

Step 7. Determine ultimate tensile strength from the Vickers hardness.

Step 8. Determine yield strength from ultimate tensile strength using an assumed correlation between yield/ultimate strength ratio.

3 DESCRIPTION OF TESTS CONDUCTED

Samples were extracted for tensile testing, hardness testing and chemical analysis. Table 1 lists the name of the bridge and the number of samples extracted and the type of test performed.

Table 1 : Reinforcement extracted and tested from various bridges

Bridge Name	Year built	No. of samples	Tensile Test	Hardness test	
				Insitu	Lab
Daley's Bridge	1937	26	✓		✓
		10	✓	✓	✓
Helendoite Road Bridge, Maroona	1913	9	✓	✓	✓
Crab hole	1937	1	✓	✓	✓
		1	✓		✓
Caringbah	1935	3	✓		✓
		2	✓	✓	✓
Lakes Channel	1934	13	✓		✓
		7	✓	✓	✓
Baranduda	1920	9	✓		
Barr Creek	1939	10	✓		
Rosedale bridges	1939	1	✓		✓
Diddah Diddah old bridge		2			✓
Fuges bridge		1			✓
Bridge over black dog creek		1			✓
South Gippsland Highway Bridge over Latrobe river floodway	1937	20	✓		✓
Bullock Creek bridge (Calder alternative highway)	1951	16	✓		
Bridge near Hobart, Tasmania	1939	6	✓		✓
Koo-Wee-Rup Longwarry Rd	1957	32	✓	✓	✓
Bradford Creek bridge	1936	28	✓	✓	✓

4 TEST RESULTS AND ANALYSIS

4.1 Yield strength and ultimate strength of reinforcement tested

The characteristic yield strength of the bars tested using a tensile test was determined using Equation 1.

Equation 1 $$characteristic\ yield\ strength = \bar{x} - ks$$

where $\bar{x}$ is the mean of the group of test results
k is a one-sided tolerance limit factor obtained from Transit New Zealand's Bridge Manual (4)
s is the standard deviation of the test results

The "k" values used for the current analysis are for 95% of the samples being higher than the characteristic yield strength and with a confidence "α" value of 0.95.

The characteristic yield strength of specimens from bridges which had more than five samples was determined. The characteristic strength of these samples are shown in Table 2. The characteristic strength of bars in bridges with less than five samples is not tabulated as the number of samples is not statistically significant.

Table 2 : Characteristics strength of reinforcement determined from tensile tests

<table>
<tr><th>Bridge Name</th><th>Year built</th><th>Mean Bar size (mm)</th><th>Number of samples</th><th>Mean yield strength (MPa)</th><th>Characteristic yield strength (MPa)</th></tr>
<tr><td>Maroona</td><td>1913</td><td>28.5</td><td>9</td><td>279</td><td>245</td></tr>
<tr><td>Lakes Channel</td><td>1934</td><td>15.9</td><td>19</td><td>302</td><td>253</td></tr>
<tr><td rowspan="2">Daley's Bridge</td><td rowspan="2">1937</td><td>12.6</td><td>30</td><td>318</td><td>283</td></tr>
<tr><td>9.5</td><td>6</td><td>302</td><td>275</td></tr>
<tr><td>South Gippsland bridge over Latrobe river floodway</td><td>1937</td><td>15.9</td><td>20</td><td>309</td><td>285</td></tr>
<tr><td rowspan="2">Bullock Creek bridge (Calder alternative highway)</td><td rowspan="2">1951</td><td>19.0</td><td>8</td><td>307</td><td>260</td></tr>
<tr><td>22.0</td><td>8</td><td>267</td><td>210</td></tr>
<tr><td rowspan="2">Koo-Wee-Rup Longwarry Rd</td><td rowspan="2">1957</td><td>18.74</td><td>16</td><td>297</td><td>249</td></tr>
<tr><td>20.9</td><td>16</td><td>308</td><td>281</td></tr>
<tr><td rowspan="2">Bradford Creek</td><td rowspan="2">1936</td><td>15.8</td><td>17</td><td>298</td><td>282</td></tr>
<tr><td>25.1</td><td>12</td><td>285</td><td>202</td></tr>
</table>

From Table 2 the characteristic yield strength of the samples was higher than 230 MPa, except for the 22 mm and 25 mm bars of Bullock Creek and Bradford Creek bridges respectively. The results support the assumption that it is conservative to assume a value of 230 MPa for the yield strength of unidentified reinforcement. If the characteristic strength of the specimens from Bullock Creek was based on a greater number of specimens with the same mean and standard deviation as the samples tested the characteristic strength would have exceeded 230 MPa. The greater number of samples might also be expected to reduce the standard deviation and result in a characteristic strength nearer to the mean.

The mean yield strength of the specimens presented in Table 2 was 300 MPa indicating that if a significant number of tests can be made to determine the strength of reinforcement and that the standard deviation of the test results is small, then there is potentially significant savings in determining the actual yield strength of the material used in a bridge compared to assuming that its yield strength is 230 MPa. Alternatively if all of the structural critical bars are tested in the bridge then the actual yield strength determined for each bar may be used in the calculations of strength. An increase of 70 MPa in the design strength of the reinforcement leads to an approximate increase of 40% in load carrying capacity for typical T beam bridges ie. Truck loads 40% greater than originally calculated may be able to be carried by the bridge. The potential gain in live load capacity is greatest for structures with higher dead load to live load ratios, such as cast insitu reinforced concrete tee beam bridges.

Based on the current test results it is not likely that a characteristic yield strength greater than 300 MPa will be obtained from testing of plain round bars from existing bridges.

A graph showing the ratio of yield strength to ultimate strength for all of the tensile tests carried out under this investigation is given in Figure 4. The data has a lower characteristic limit of 0.57 (based on P and α equal to 0.95).

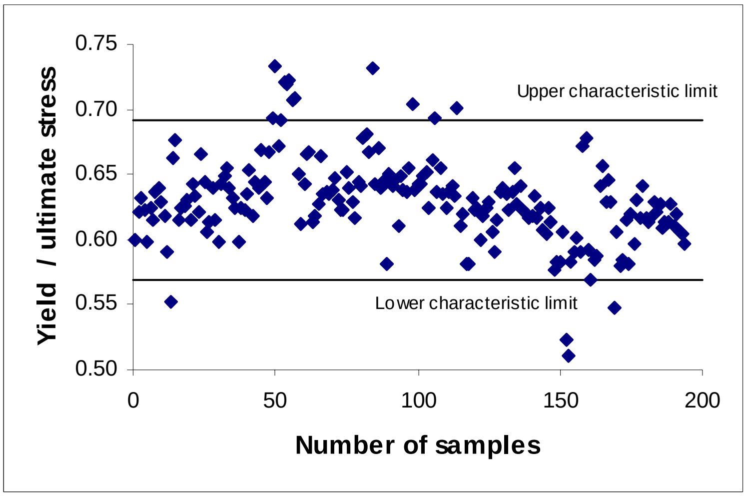

Figure 4: Ratio of yield strength to ultimate strength

The relationship between yield strength and ultimate strength may be used with a relationship between hardness and ultimate strength in order to predict the yield strength of bars from hardness tests.

4.2 Hardness test results

The hardness of bars were tested onsite using the Equotip portable hardness tester. Tests were also conducted in the laboratory using a laboratory based test machine. The results are shown in Table 3.

The purpose of the laboratory based testing was to check between site based measurements and laboratory based measurements.

Table 3 : Hardness test results

Bridge Name	Mean Bar size (mm)	Number of samples	Mean Vickers hardness (on site)	Mean Vickers hardness (laboratory)
Koo-Wee-Rup Longwarry Rd	18.7	16	134	140
	20.9	16	143	142
Bradford Creek	15.8	17	102	148
	25.1	12	132	139

The test results in Table 3 show reasonable correlation for three out of the four bar sizes tested. The 15.8 mm bar size did not give consistent results. After discussions with Opus it was found that they have also had difficulties with smaller bar sizes (sizes less than 19 mm).

The Vickers hardness test results have been converted to Ultimate stress values using a conversion table given in Machinery's Handbook (5).

Table 4 : Comparison of hardness to ultimate strength

Bridge Name	Mean Bar size (mm)	Ultimate stress from on site Vickers hardness test	Ultimate stress from laboratory Vickers hardness test	Mechanical test result
Koo-Wee-Rup Longwarry Rd	18.7	460	480	477
	20.9	490	490	483
Bradford Creek	15.8	360	510	492
	25.1	460	480	498

The ultimate strength values in Table 4 were converted to yield stress values using the lower characteristic ratio value determined in Figure 4 (the value used was 0.57). The estimated yield strength of the bars are compared with the actual values in Table 5.

Table 5 : Estimated and actual yield strength of reinforcement

Bridge Name	Mean Bar size (mm)	Yield stress from on site Vickers hardness test	Yield stress from laboratory Vickers hardness test	Yield stress from Mechanical test result
Koo-Wee-Rup	18.7	262	274	298
Longwarry Rd	20.9	279	279	285
Bradford Creek	15.8	205	290	297
	25.1	262	274	308

5 CONCLUSIONS

By testing reinforcement taken from pre 1960 bridges it was observed that the average yield strength was 30% higher than the manufactures specifications. The results indicated that many of the pre 1960 bridges may have reserve capacity due to this factor.

Using the test results a procedure was developed to convert the on site hardness test results to yield strength. The lower characteristic ratio of yield strength to ultimate strength of the specimens tested was 0.57. When a conversion from hardness to yield strength is made using this ratio the estimated yield strength is likely to be less than 30% higher than the manufactures specification for plain round bar reinforcement extracted from pre 1960 bridges. The results on all samples have proved to be conservative.

The use of on site hardness testing is recommended if the yield strength of the reinforcement is unknown in an existing bridge which requires assessment. On site hardness testing is particularly worthwhile if increases of capacity of up to 15% are required based on assessment which were made assuming 230 MPa steel.

Further work is continuing involving testing of in-service bridges to improve the methodology for selecting and performing hardness tests on critical sections of reinforcement.

6 REFERENCES

1 STANDARDS AUSTRALIA. “Australian Bridge Design Code”. SAA HB77.0, Sydney, NSW 1996.

2 STANDARDS AUSTRALIA/ STANDARDS NEW ZEALAND. “AS/NZS 4671”. BD-084, Sydney, NSW 2001.

3 BRUCE S. M.. “Determination of yield strength by hardness testing of reinforcing steel in bridges”. Opus International Consultants, Report to VicRoads, May 2001

4 Transit New Zealand Bridge Manual, Dec 1999., pp 6-8 to 6-9.

5 Machinery’s Handbook, Revised 21st Ed., Industrial Press, 1979