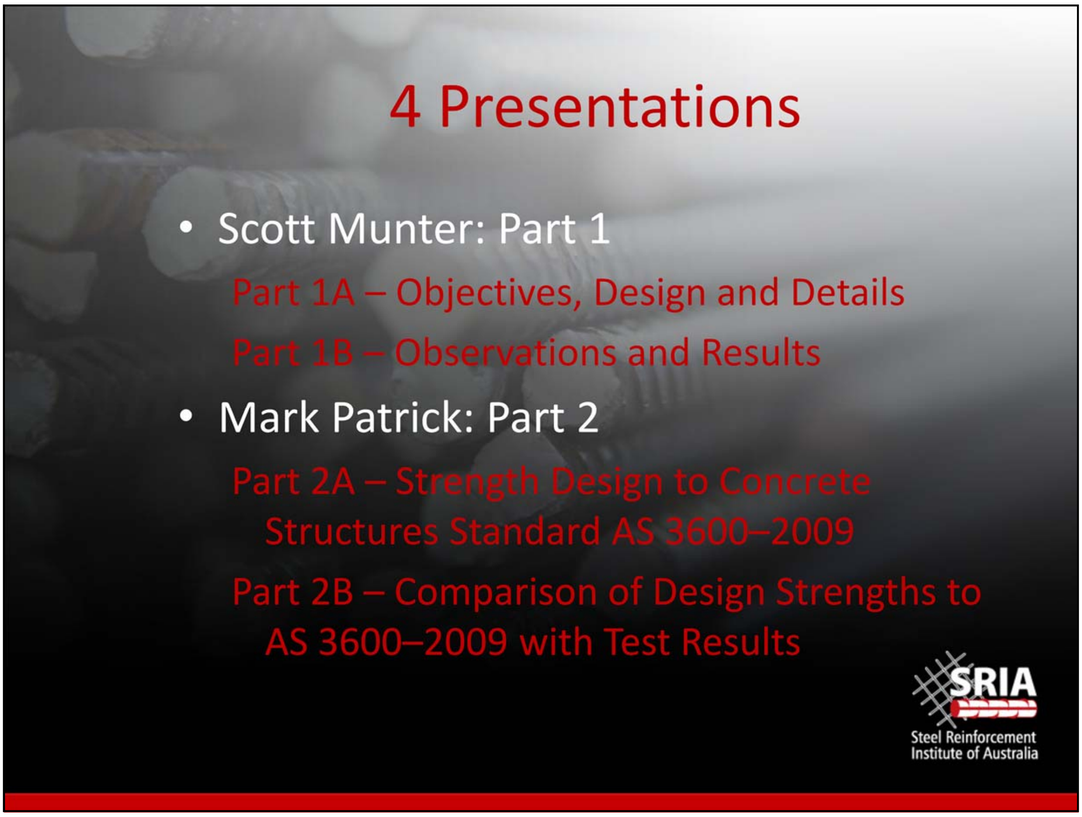
Two papers, each in two parts A and B, will be covered in the next four presentations regarding the SRIA's Class L Mesh Elevated Slab Tests conducted at Curtin University as an industry-funded research project initiated 5 years ago, which is now complete.

The first presentation, Part 1A, will cover the Objectives, Design and Details of the research program and test slabs.



The titles of all four presentations are shown here.

I will also present Part 1B covering Observations and Results obtained from the testing.

My co-author will present Parts 2A and 2B, which specifically cover the strength design of the test slabs to AS 3600–2009, and then compare the design strengths with the test results.

This slide shows SRIA's Peer Review Panel, who were charged with overseeing the conduct of the research project, witnessing a test at Curtin University.

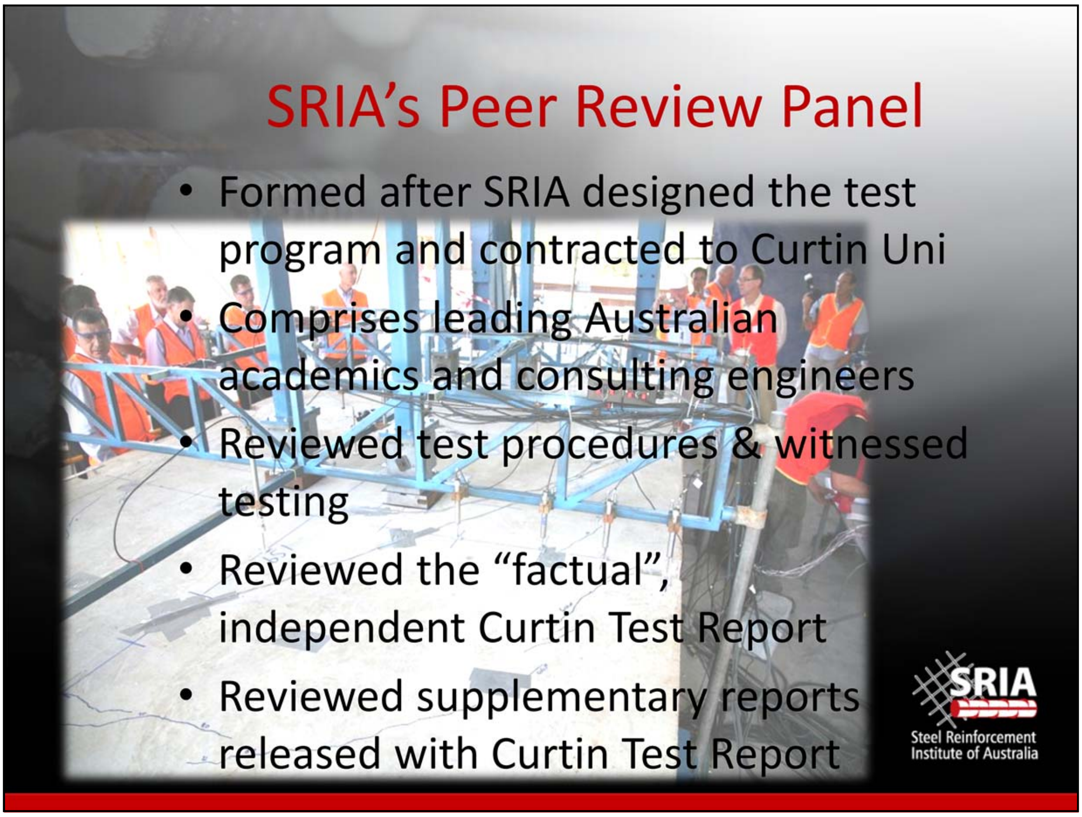
The work of the two principal researchers, Dr Ian Chandler (in yellow) and Dr Natalie Lloyd (in maroon), overcame a number of technical difficulties to successfully complete the complex experimental work.

The Curtin Test Report on the SRIA Class L Mesh Slab Tests is now available in three substantial volumes.

Volume 1 of over 170 Pages contains the Report.

Volume 2 contains additional plates or photographs of the test slabs during testing.

Volume 3 contains primary graphs of the extensive test data.

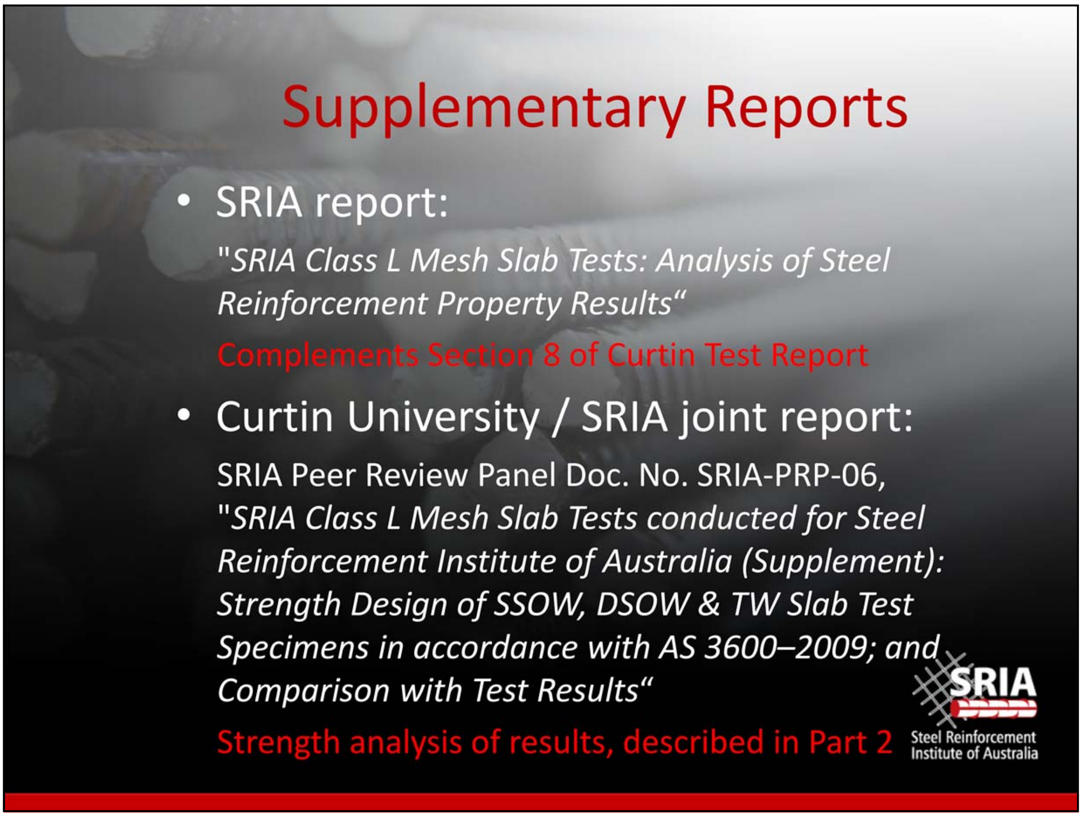


In 2008 SRIA established the Peer Review Panel, after the test program was designed and Curtin University had been engaged.

It comprises some leading Australian academics and consulting engineers experienced in reinforced-concrete design.

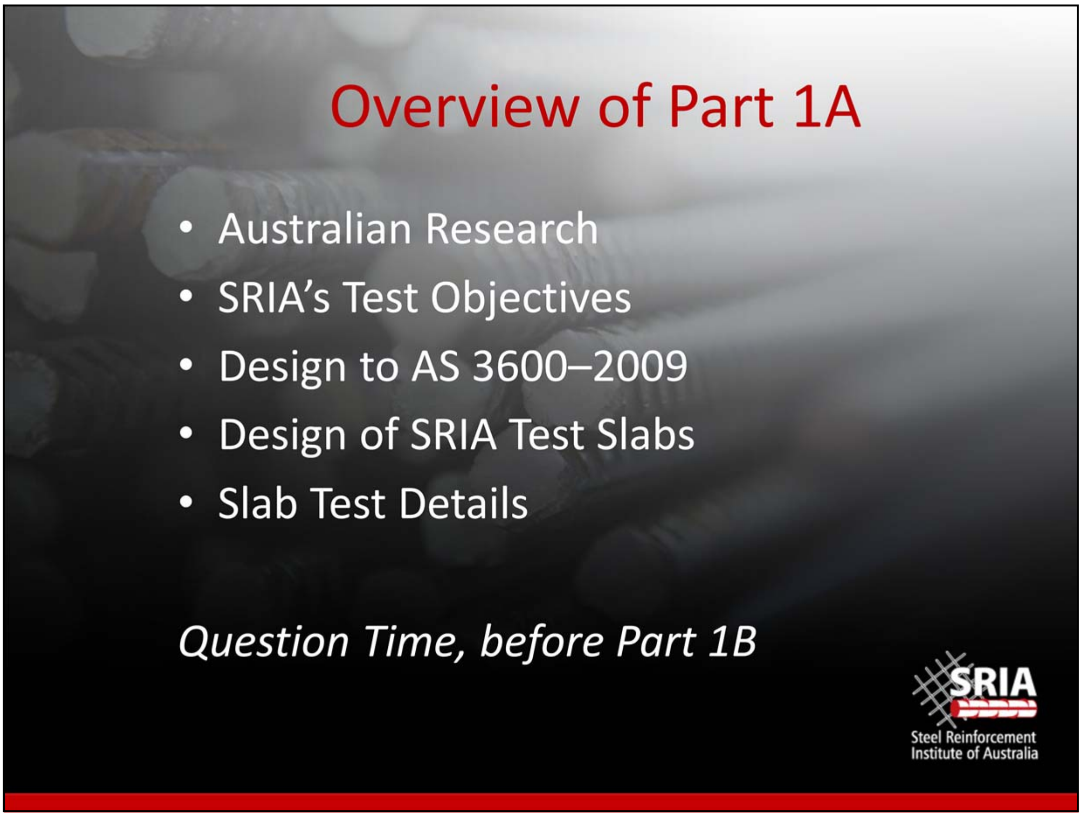
Over the past 4 years they have reviewed all the proposed test procedures, and witnessed some of the testing.

They have each reviewed the independent Curtin Test Report, and also two important supplementary reports released with the Curtin Test Report.



An SRIA report complements Section 8 of the Curtin Test Report and is about the steel reinforcement properties.

A joint Curtin University / SRIA report describes a strength analysis of the test results, and is described in the Part 2 presentations to follow shortly.

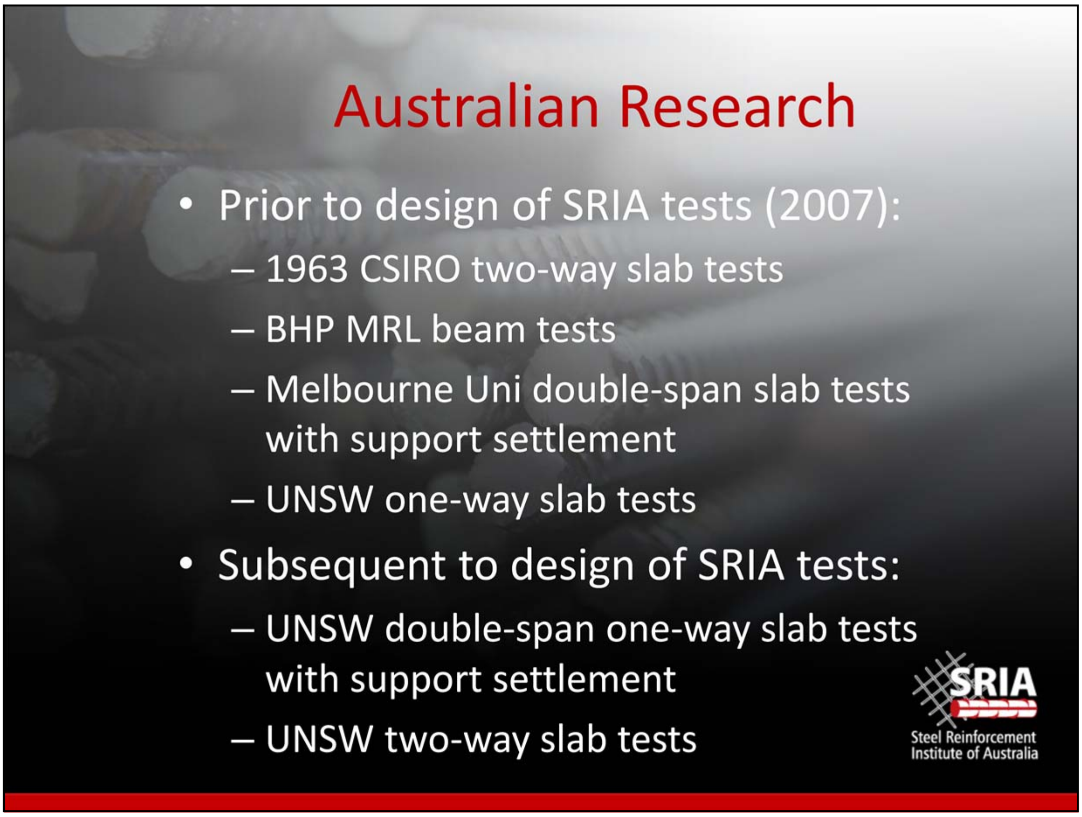


In the Part 1A presentation I will firstly cover previous Australian Research on the topic, as well as describing SRIA's comprehensive test objectives.

In 2007, AS 3600–2001 had been amended concerning the design of slabs with Ductility Class L mesh, and there was no effective change moving to AS 3600–2009. The design of the test slabs will be described referring to the latest standard.

I will also briefly describe some details of the test set-ups and test specimens.

There will be a short period for questions at the end of each presentation.

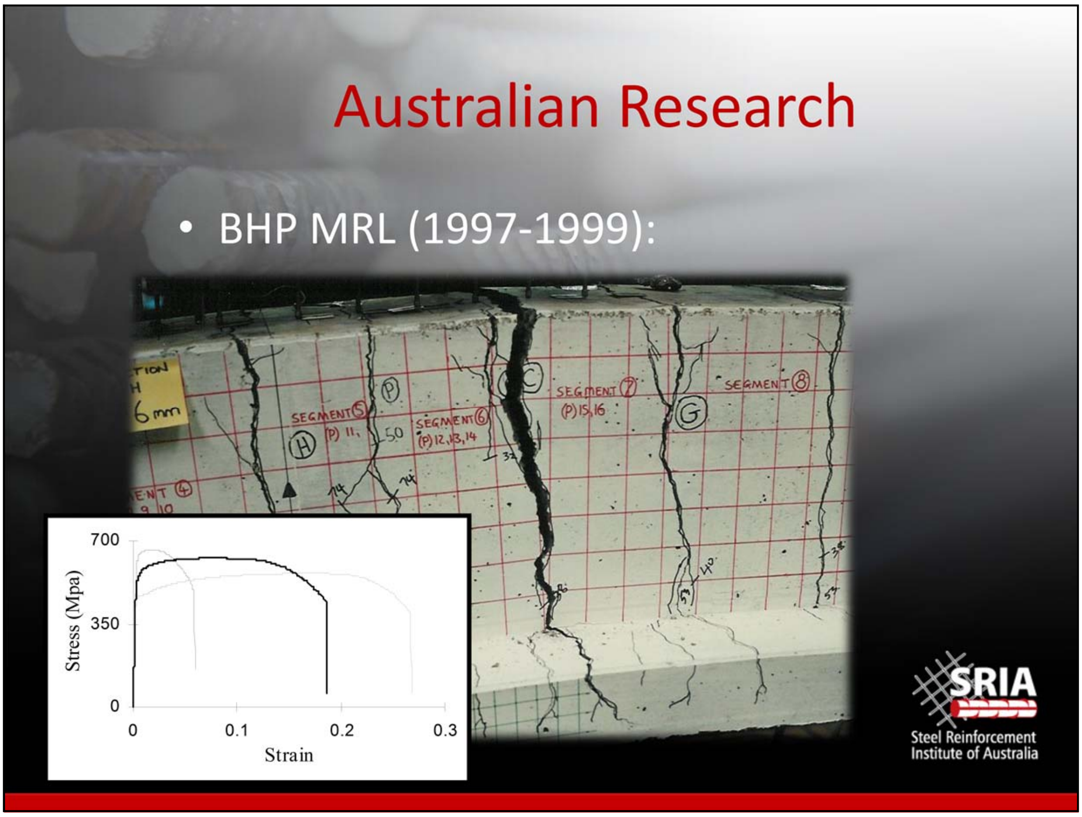


Predating the release of Class L mesh in 2001, Blakey performed full-scale laboratory tests on two-way slabs with mesh back in the 1960's but didn't report on the steel properties. Large rectangular beams incorporating low ductility bars were tested by BHP for the BD-002 Concrete Structures committee which helped with the move to Grade 500 MPa reinforcing steels and the introduction of Class L and N reinforcing steel grades into AS 3600–2001.

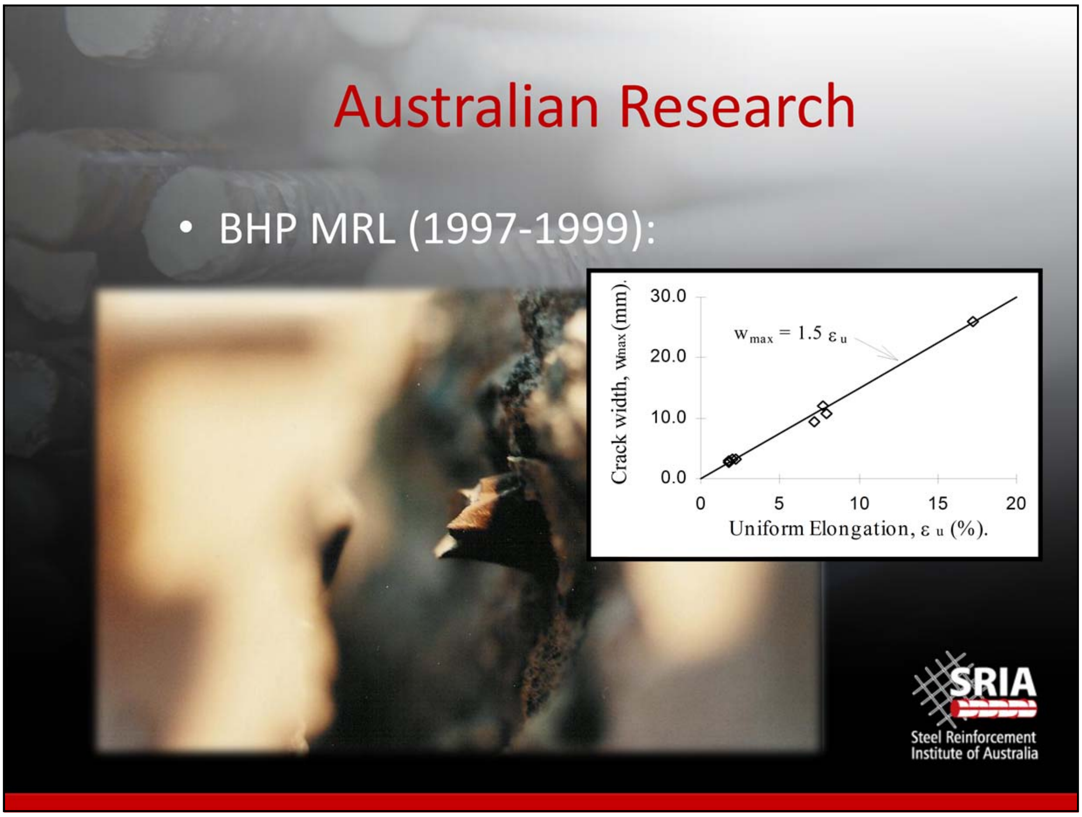
When the SRIA research project was developed early in 2007, two double-span tests had been performed at Melbourne University to study the effects of support settlement. Fifteen single and double-span slabs had been tested at the University of New South Wales.

SRIA decided to undertake some double-span slab tests with support settlement, and responding to requests from the BD-002 committee SRIA also designed a two-way slab test.

The UNSW has subsequently published the results of some similar tests on slabs incorporating Class L mesh.

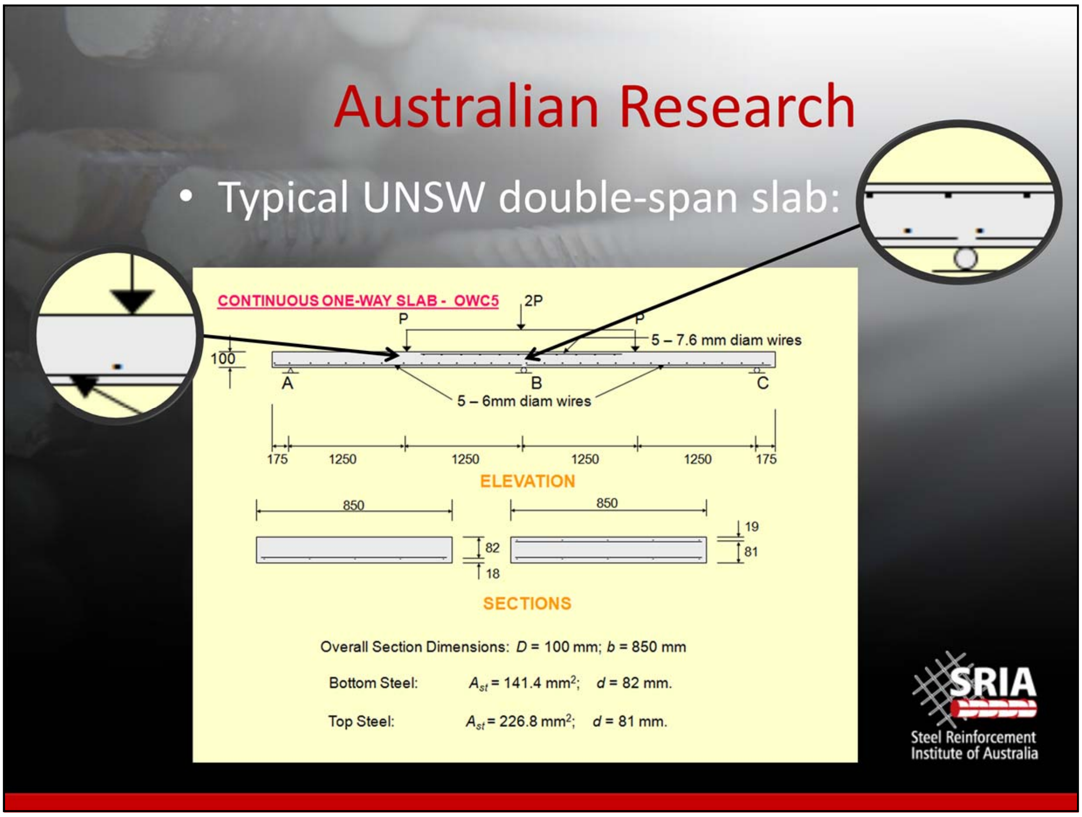


BHP also tested some large T-beams incorporating steel bars of widely different ductility, as seen from these stress-strain diagrams.



Steel fracture was a natural phenomenon in all of the BHP tests, with steel ranging from Class L to N.

A linear relationship was established between crack width at ultimate load, at the depth of the bars, and uniform elongation or strain of the steel. This is useful to bear in mind when studying flexural cracks.



This is a typical double-span slab tested at UNSW pre 2007. It differs from the SRIA double-span slabs, which have continuous top and bottom layers of mesh.

In the Part 2 presentations we'll explain why we believe the SRIA slab cross-sections doubly-reinforced with Class L mesh are significantly stronger in bending.

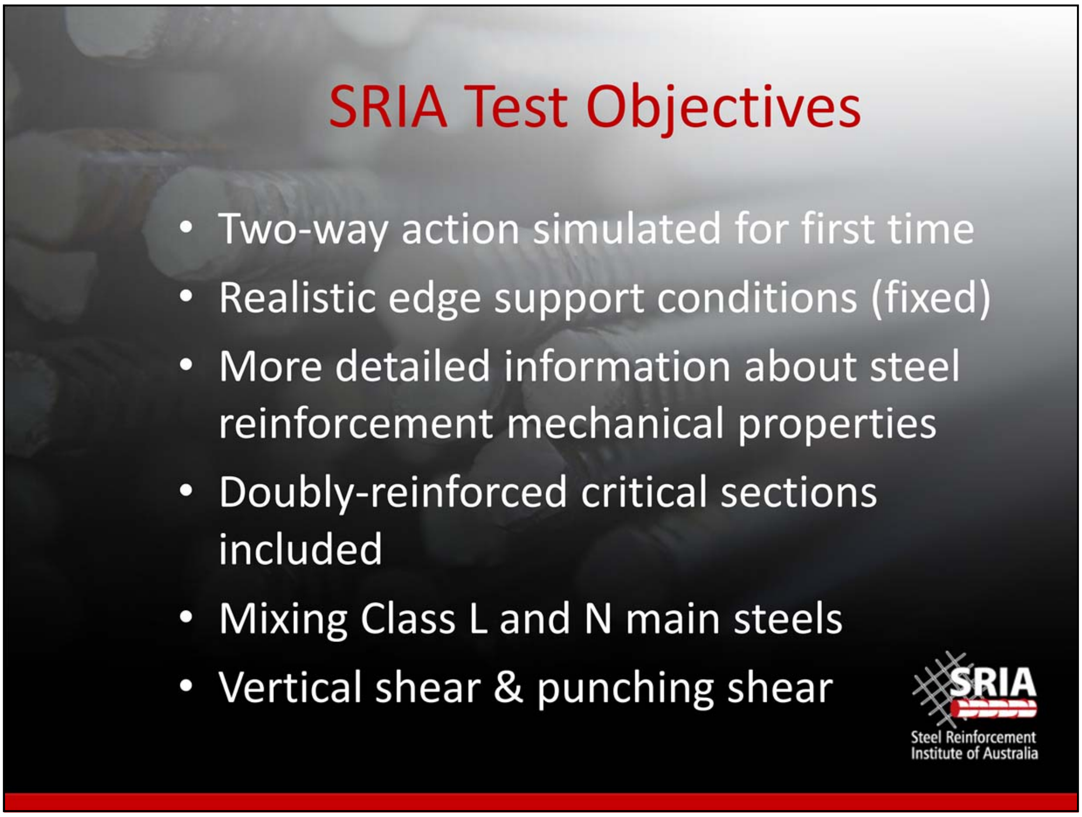
These objectives of the SRIA tests are explained in the paper, and are also included in an Addendum to the Curtin Test Report.

The SRIA Board insisted that the slabs were designed and detailed strictly in accordance with AS 3600–2009. Slabs supported on rollers do not satisfy the detailing requirements of AS 3600. Nevertheless a number of the slabs were still supported this way so they were statically determinate, making it possible to calculate the bending moment and shear force diagrams at any stage of loading. Otherwise, the test slabs had their ends or edges well restrained, and it is these specimens that strictly conformed to the Standard and could therefore represent real behaviour in a normal building.

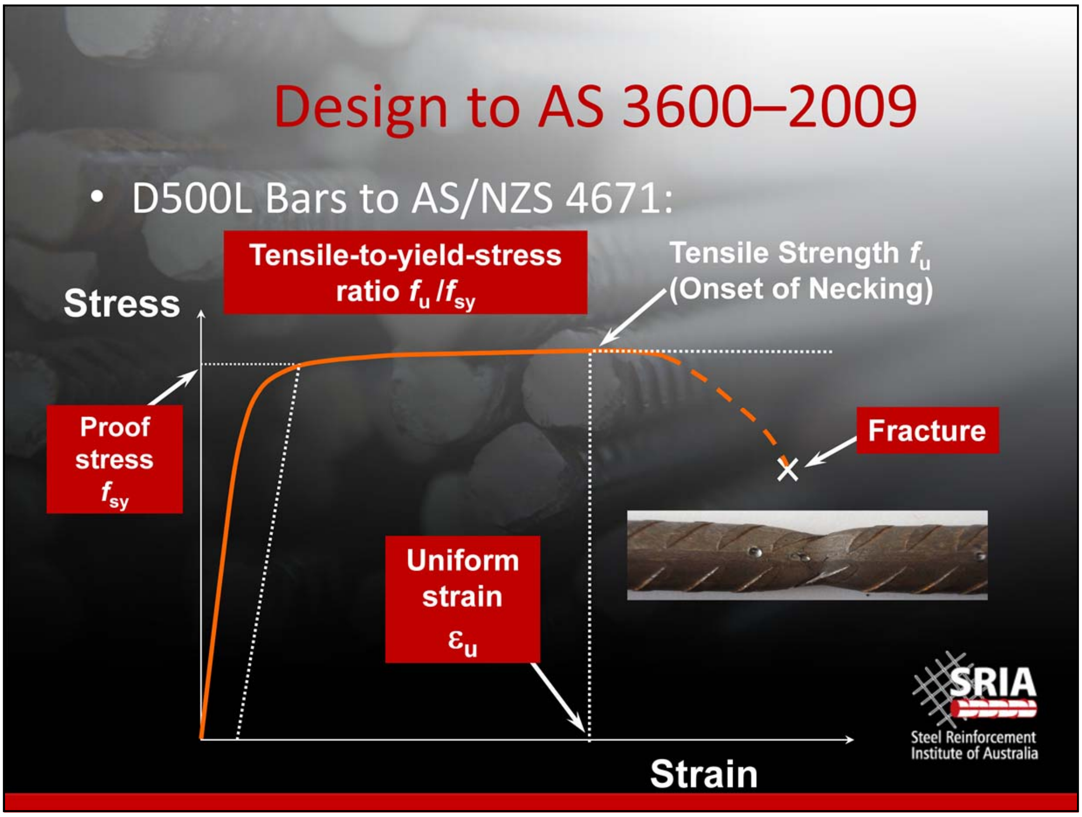
Typical Class L mesh was sourced rather than attempting to manufacture mesh of the lowest acceptable ductility, which would have been very difficult.

Serviceability conditions were simulated, but ultimate strength and behaviour were the paramount focus given the concerns raised by academics about these issues.

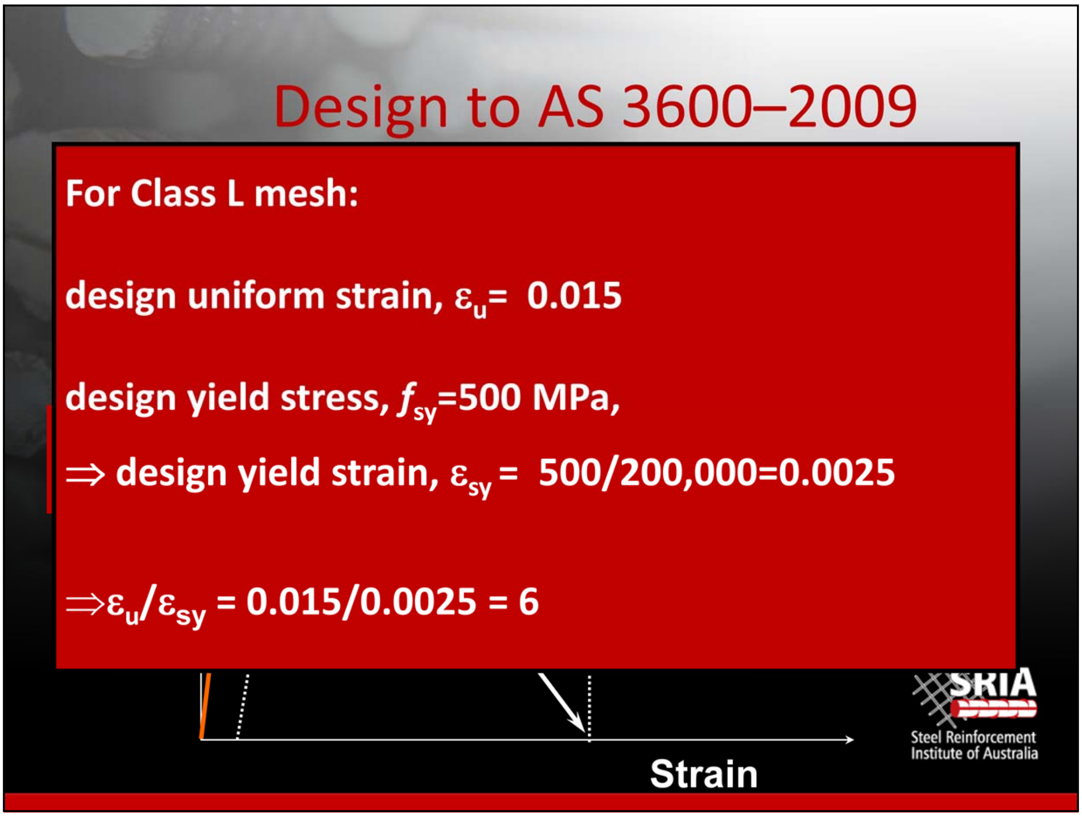
The inherent ductility of slabs incorporating Class L mesh and their ability to accommodate moment redistribution was to be studied after the effects of significant support settlement



As covered in the paper, all of these factors were to also be instigated or studied……



Tensile-to-yield stress ratio and uniform strain are used to define the ductility of reinforcing steels.

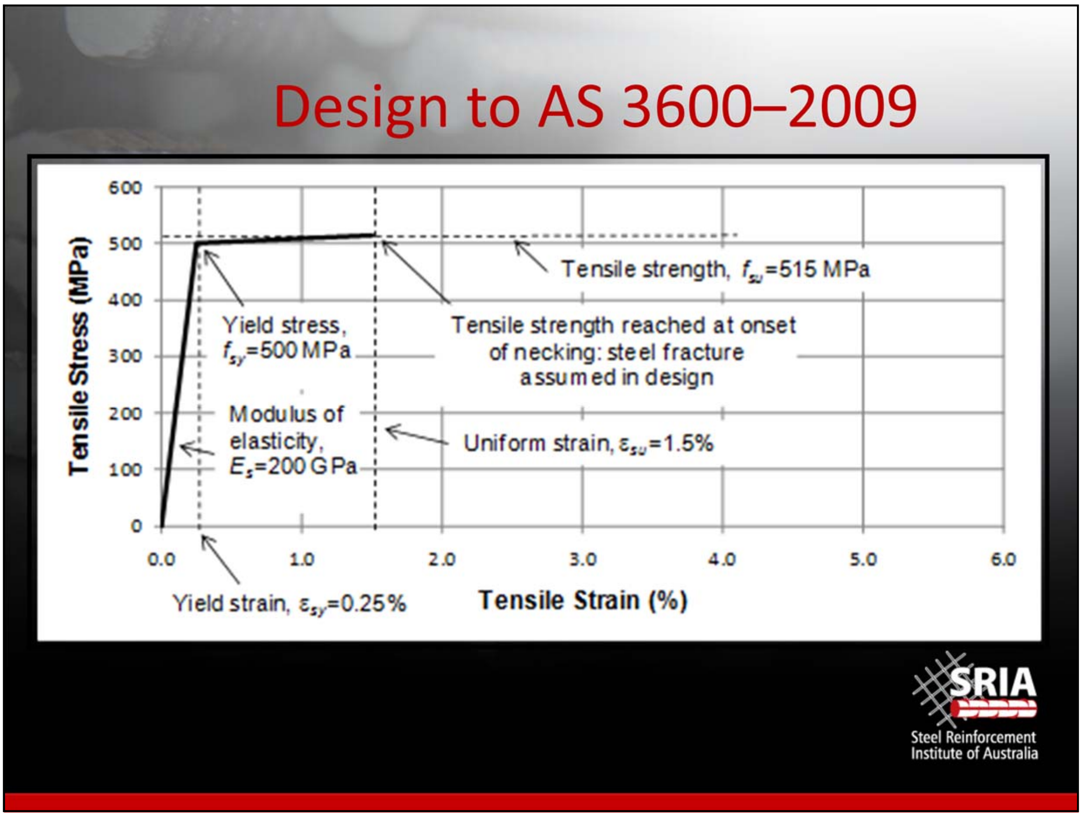


For Class L mesh, the design uniform strain, ε_u, may conservatively be taken to equal 1.5% or 0.015, the minimum value permitted.

With a design yield stress of 500 MPa, the design yield strain equals 0.0025.

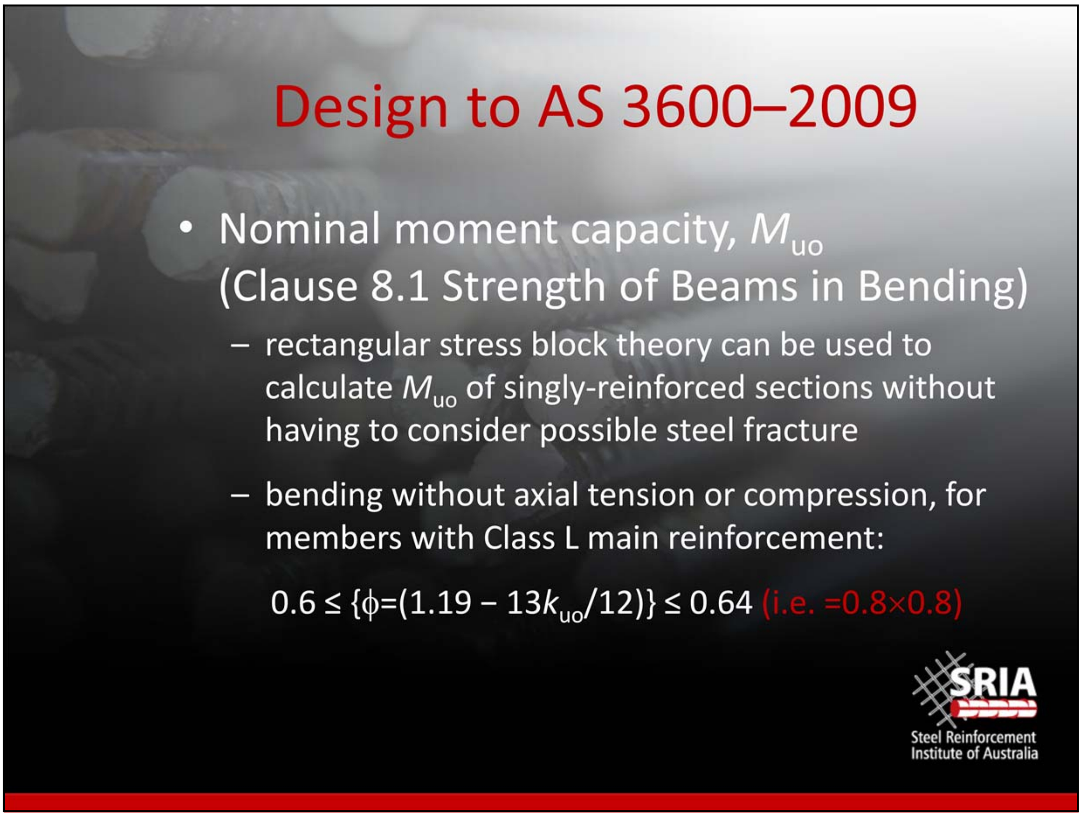
Therefore, the ratio of design uniform strain, which in design is when bar fracture may be assumed to occur, to the yield strain is 6. With this level of ductility, moment-curvature analysis shows that the full bending strength of under-reinforced, singly-reinforced sections will be reached.

In the paper, Clause 1.1.2 Application of AS 3600–2009 is considered. It is meant to act as a warning that Class L mesh has limited ductility, and should not for example be used in plastic design if excessively large amounts of moment redistribution are required at the strength limit state.



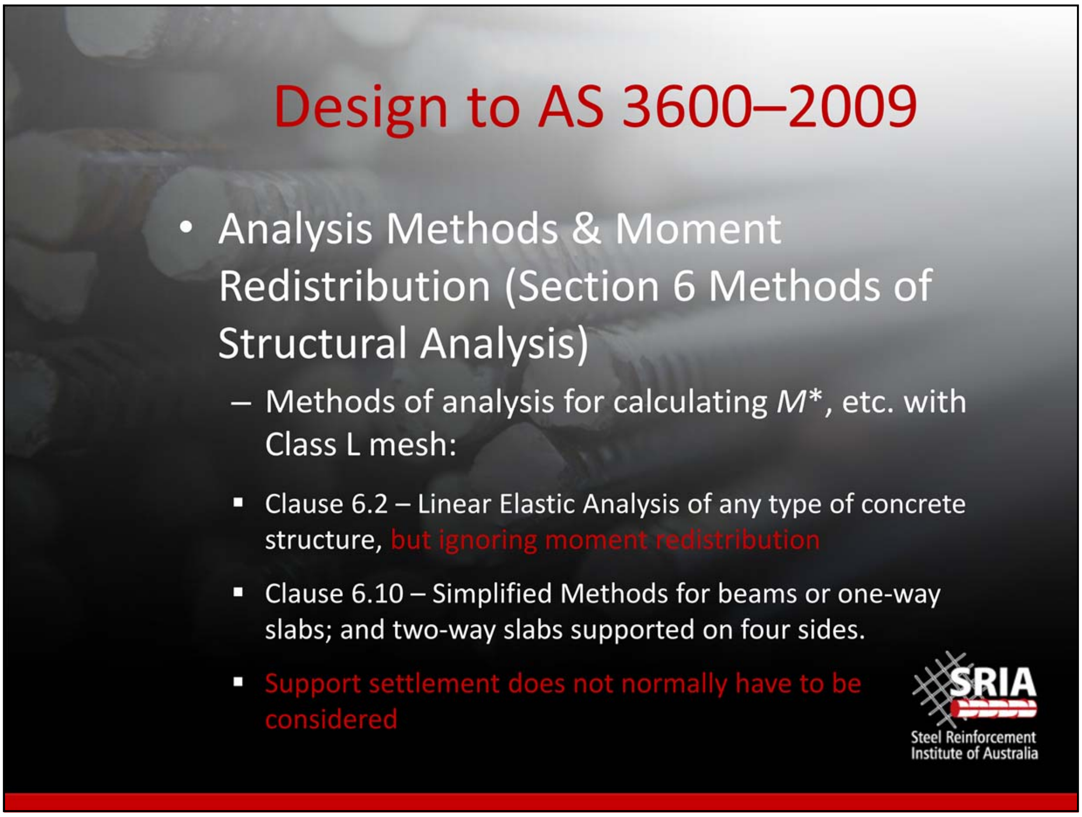
It is explained in the paper that Clause 1.1.2 does not disallow designers assuming that the main tensile bars of Class L mesh can reach their uniform strain without failing.

Nowhere in the Standard was there any specific mention of Ductility Class N and L reinforcing steels being used together as main reinforcement, while this commonly occurs in practice.



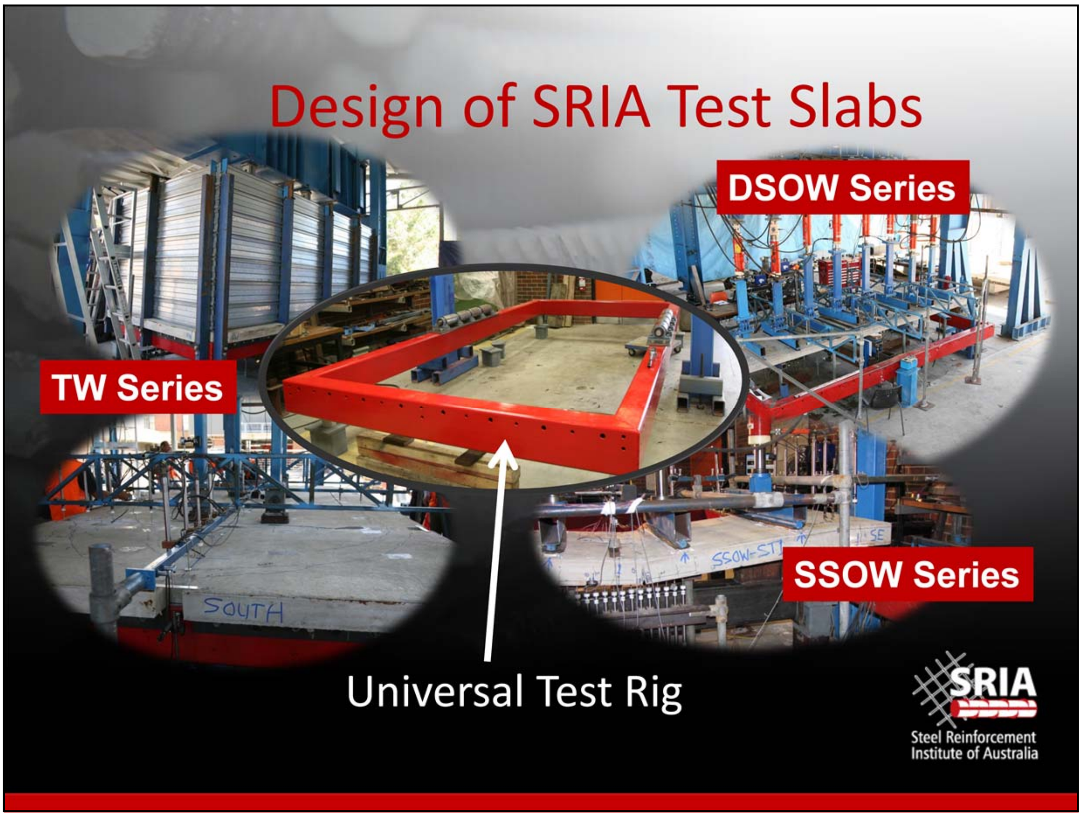
Rectangular stress block theory can be used to calculate the nominal moment capacity of singly-reinforced sections containing Class L or N reinforcing steel without having to consider possible premature steel fracture. This is due to their ductility.

In the case of bending without axial tension or compression, with Class L main reinforcement the maximum value of ϕ has been reduced to 0.64 with a 20% penalty applying for under-reinforced sections with k_{uo} not exceeding 0.36.



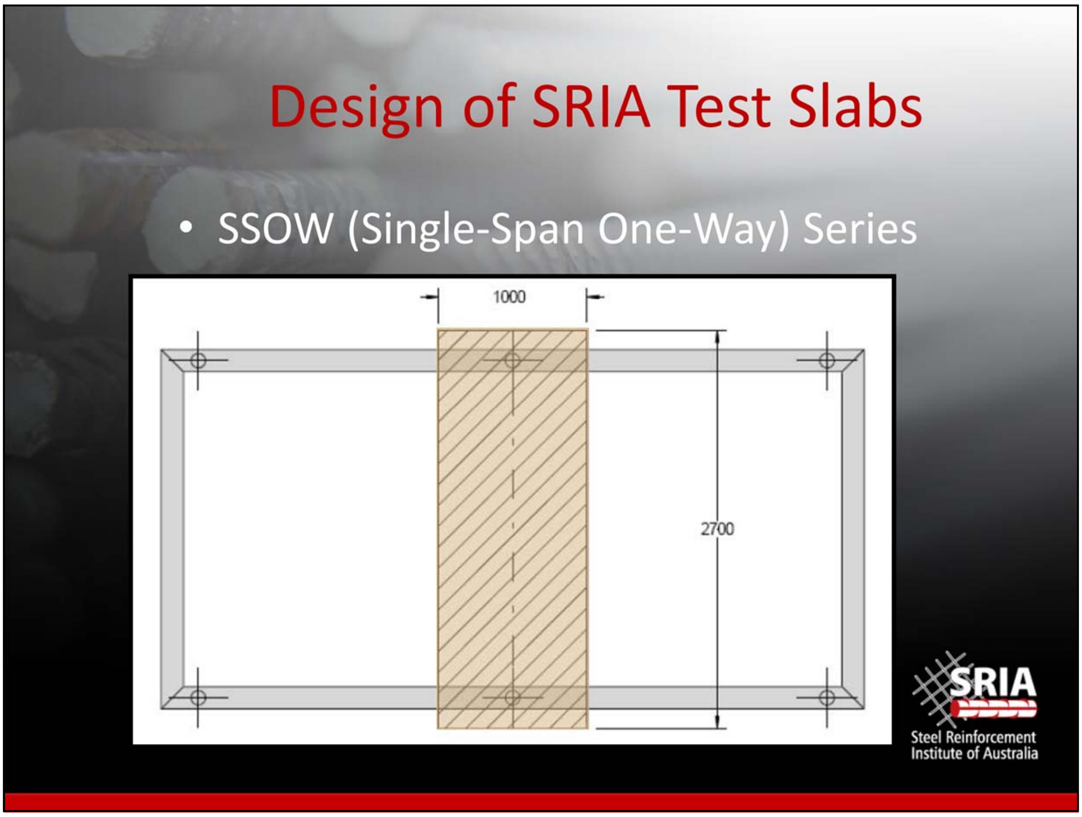
Some of the methods of analysis permitted to be used with Class L mesh present are linear elastic analysis ignoring moment redistribution, and the simplified methods of flexural analysis. Support settlement does not normally have to be considered as a design action.

Other acceptable methods of analysis will be discussed in the Part 2 presentations.

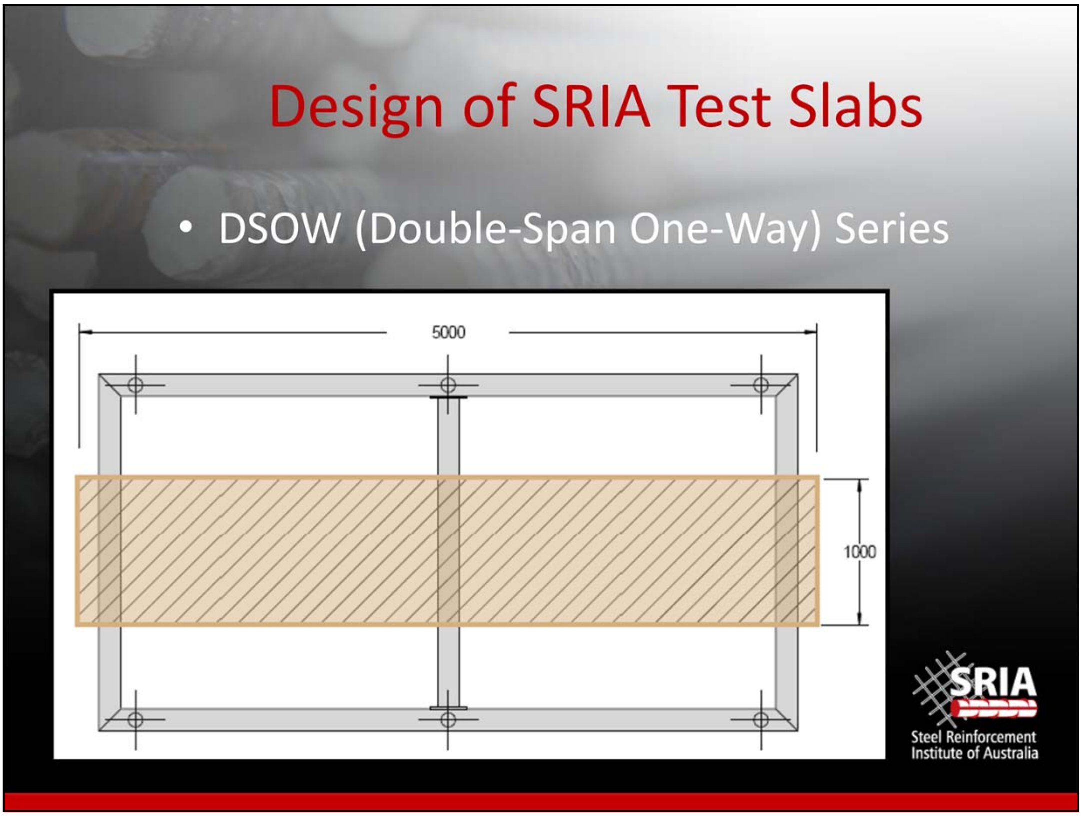


A universal test rig was designed to be used multiple times when testing three series of slabs: SSOW – Single-Span One-Way; DSOW – Double-Span One-Way; and TW – Two Way. All the slabs were nominally 110 mm deep.

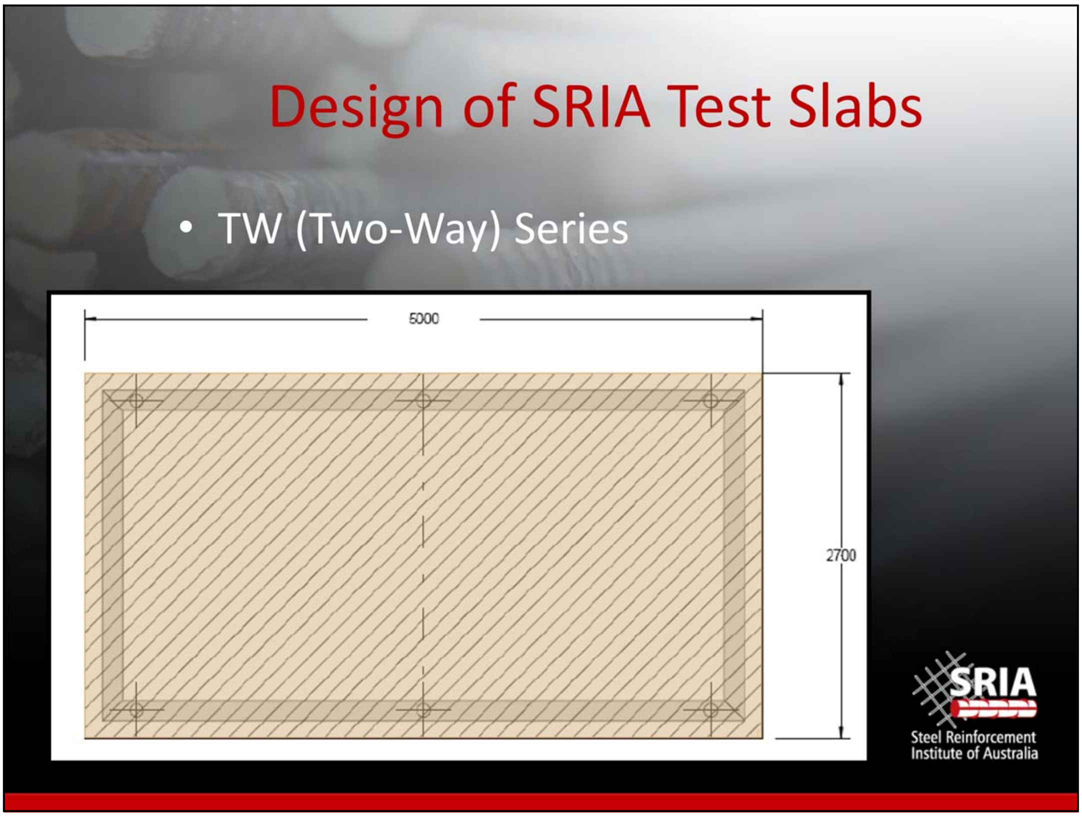
A key element of the test rig was a high-tensile, tubular steel ring beam, which could act like a deep monolithically-cast concrete edge beam to provide fixity to the ends or edges of the test slabs when required. Therefore, only flat slab test specimens had to be poured.



All of the SSOW slabs spanned across the short dimension of the ring beam. The slabs were all 2700 mm long and 1000 mm wide.



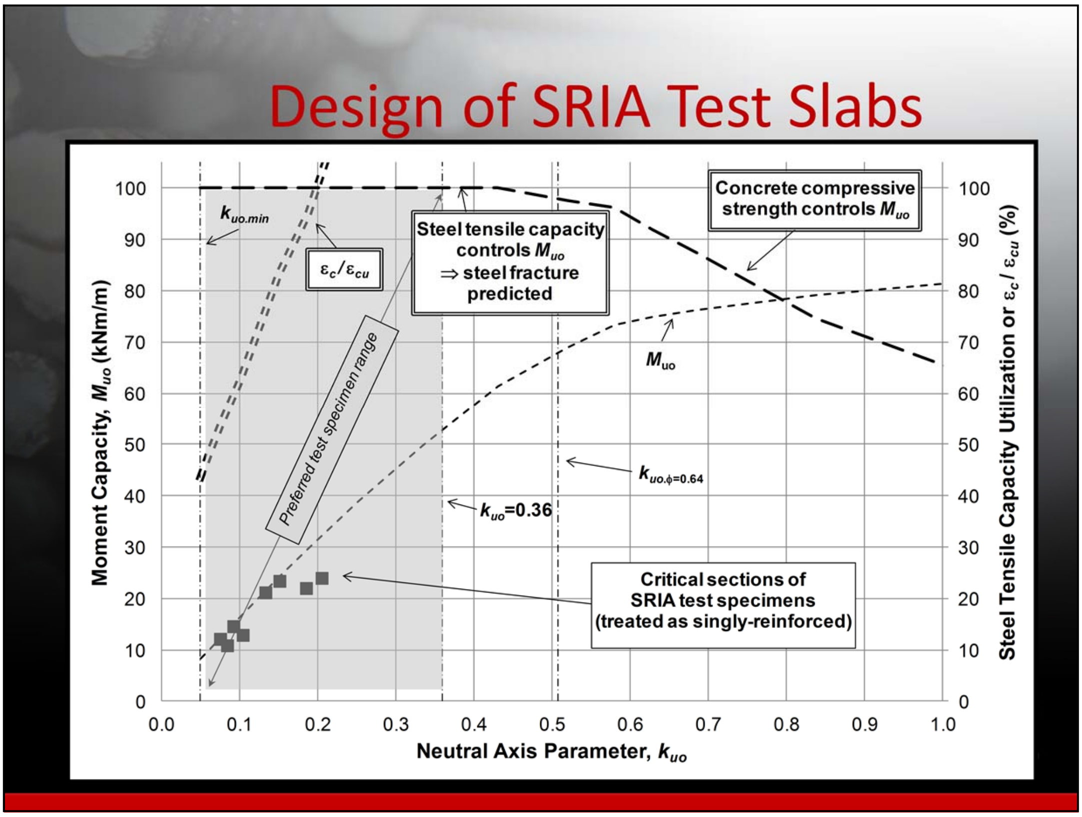
All of the DSOW slabs spanned across the long dimension of the ring beam, with a central support member added. The slabs were all 5000 mm long and 1000 mm wide.



A two-way slab was constructed that was 5 metres by 2.7 metres overall, with an aspect ratio of 2.

All of the simply-supported SSOW slabs were singly-reinforced. These slabs were statically determinate.

One SSOW slab with restrained ends, and all of the DSOW slabs and a TW slab, were doubly-reinforced.

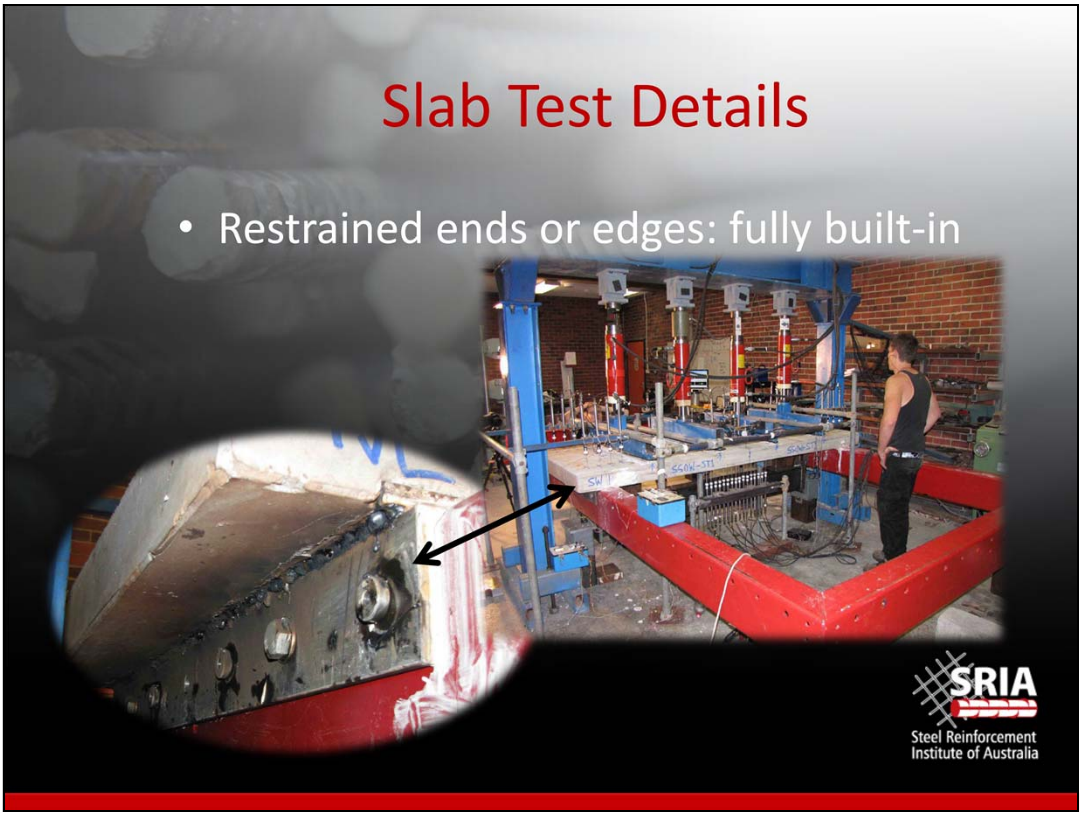


When detailing and designing the slab cross-sections for flexure, it was important that “steel ductility was tested”.

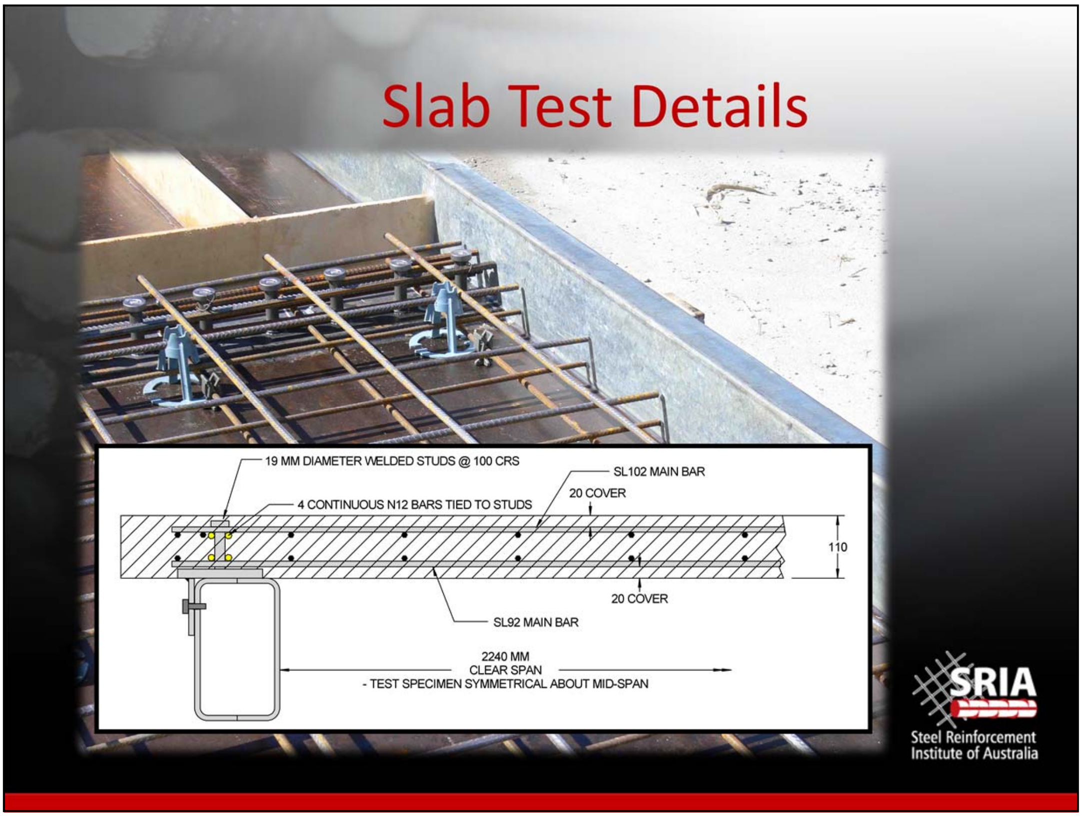
This graph shows the design relationship between moment capacity and neutral axis parameter. In the shaded “Preferred test specimen range” steel tensile capacity controls, and steel fracture is predicted. All of the test specimens were under-reinforced and fell in this range, as shown by the square boxes. M_{uo} exceeded 1.2 times the design cracking moment.

Moment-curvature analysis, using the design bi-linear stress-strain curve for the steel shown earlier, confirmed that it would fracture, and that at peak moment the concrete could be relatively lowly stressed.

Ends referred to as “unrestrained” were supported on specially-made roller bearings attached to a fixed shaft. Therefore, the ends were free to rotate about the shaft axis and move longitudinally. Note the cast-in steel plate sandwiched between the slab soffit and the bearing.



So-called “restrained ends or edges” were created by welding a vertical plate to the plate attached to the slab soffit, and then bolting and pinning it to the ring beam.



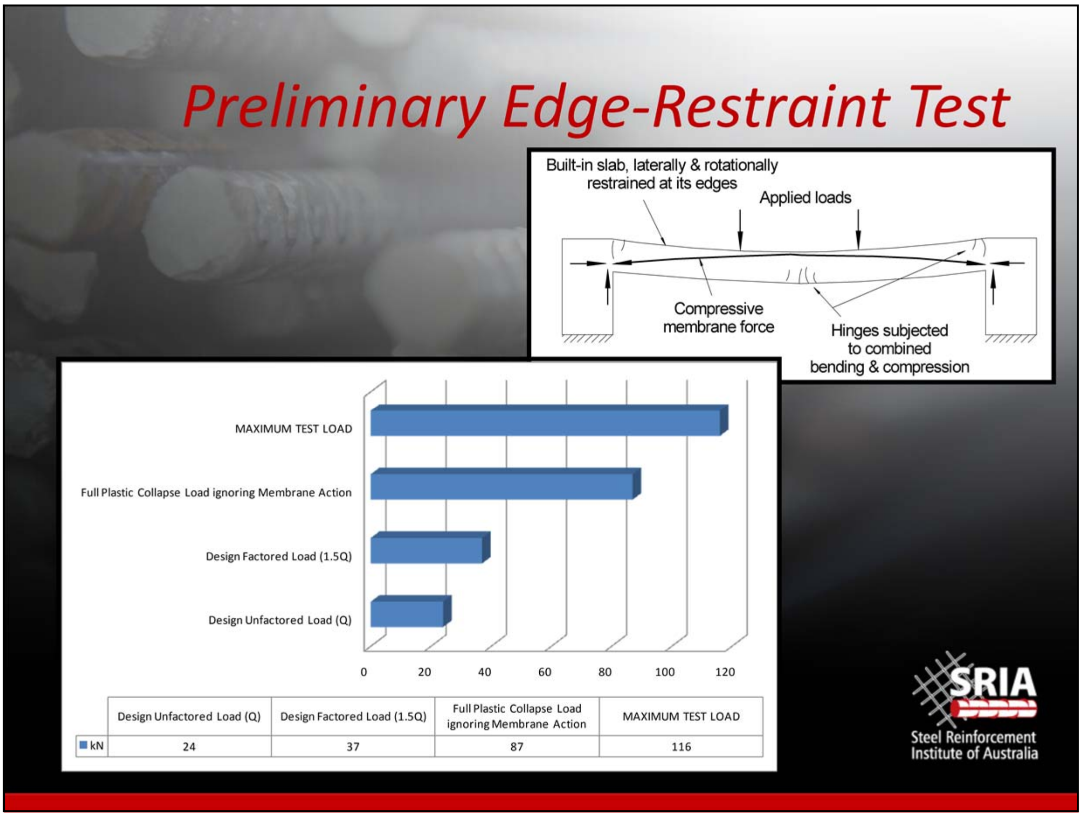
This slide shows how the restrained ends or edges of a slab were specially detailed, the intention being to achieve close to full fixity, which would require the top main bars of the mesh to be fully anchored at the end or edge.

Before pouring any of the slabs for the SSOW, DSOW or TW test series, a Preliminary Edge-Restraint Test was performed to ensure that no secondary failure modes would occur.

This test was conducted before the ring beam had been fabricated, and therefore a rigid temporary frame was assembled to which the slab was attached with restrained ends.

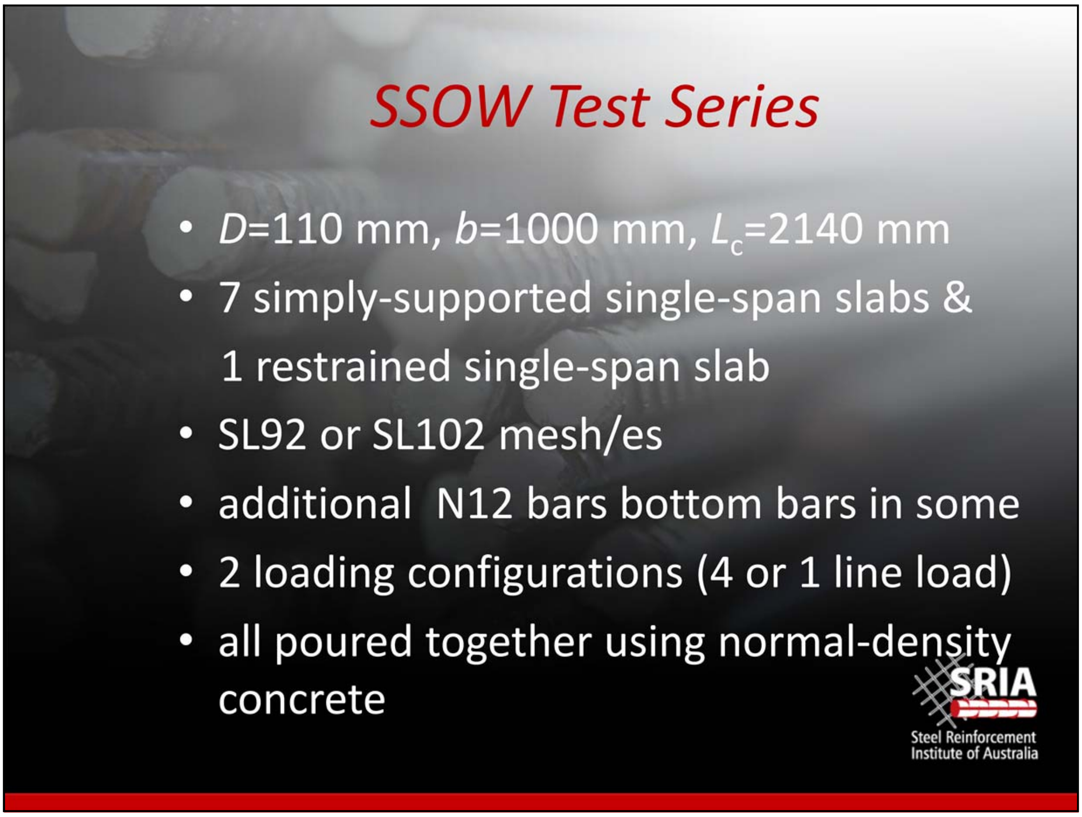
These photographs show the slab after the applied load was fully released. The main tensile bars had broken in the positive and negative hinge regions. This confirmed that the edge restraint detail was suitable for the main test series.

Notice the crushed concrete at the mid-span positive hinge, where it was estimated that the resultant compressive force had reached a maximum of over 400 kN.

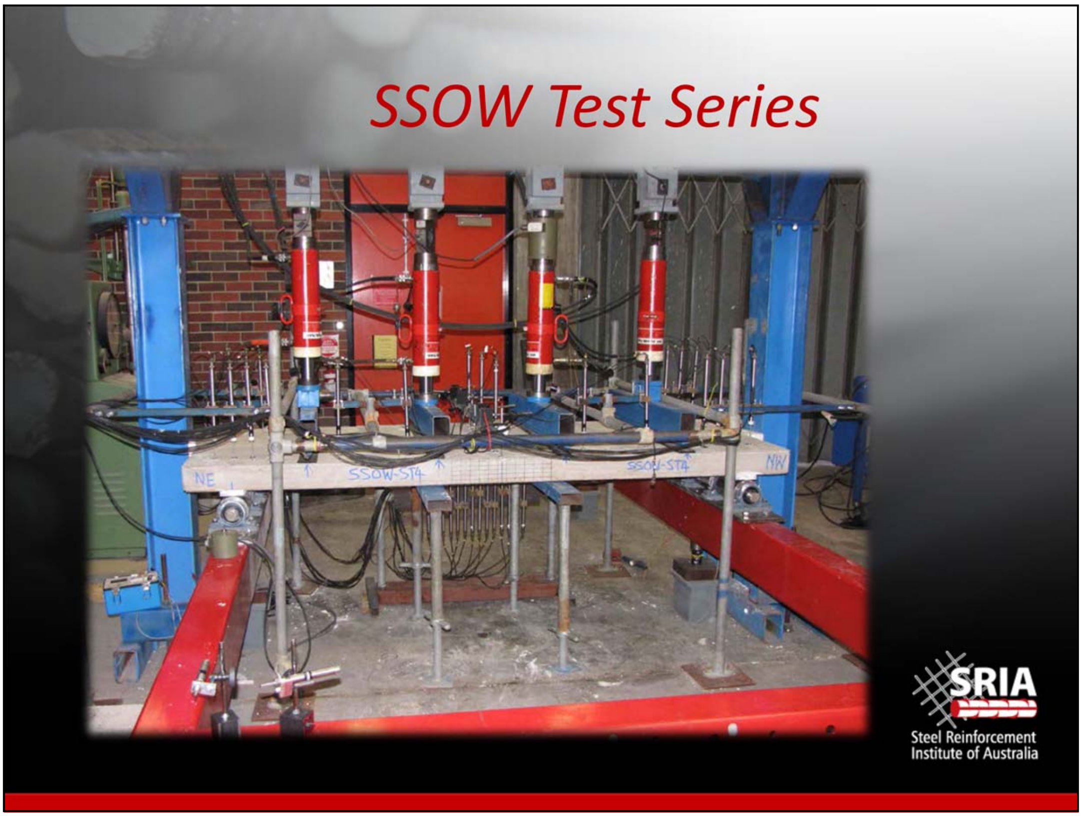


The fact that the positive hinge occurred at mid-span rather than under the loading points confirmed that compressive membrane action had developed, as explained by the top figure.

The bar chart shows that the maximum test load of 116 kN was much greater than the design factored load of 1.5Q which was 37 kN, and even well exceeded the full plastic collapse load calculated ignoring membrane action.

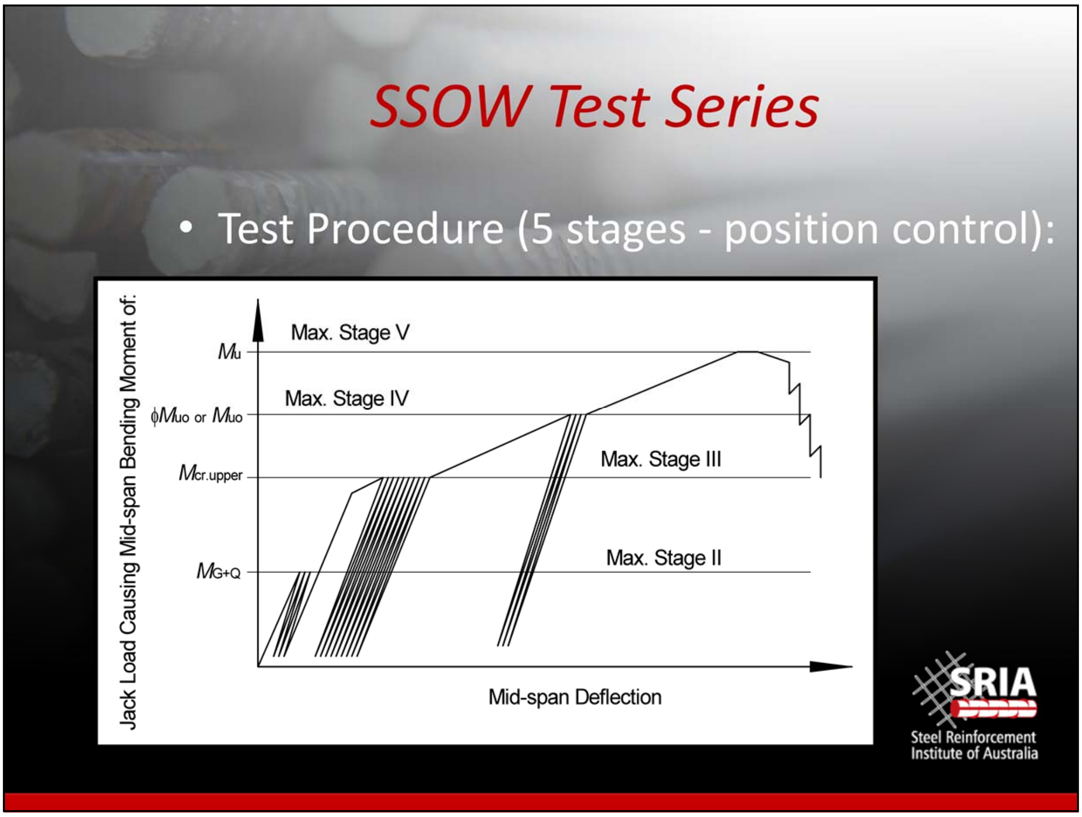


These details broadly describe the SSOW test series. L_c is the nominal clear span measured between inner edges of the steel frame.



This shows a typical test set-up of one of the simply-supported slabs with its ends supported on the rollers, and with four line loads to simulate uniformly-distributed design loading.

The four hydraulically-coupled jacks were operated in position control, suspended off the loading frame to avoid loading the slab with their dead load, and pinned at their tops to avoid longitudinally restraining the slab.



The test procedure involving 5 stages of loading was devised to initially determine a slab's flexural stiffness before cracking the concrete, then examine its performance with the full design live load Q applied, carefully induce flexural cracks along the slab and successively attach crack gauges to monitor their width, then load the slab to its design ultimate, and finally through to failure under position control so that the effects of successive bar fracture could be monitored.

DSOW Test Series

- D=110 mm, b=1000 mm, L_c=2145 mm
- 4 double-span slabs (2 restrained)
- SL92 bottom and SL102 top
- 4 line loads per span
- L'/480 (5mm) centre support uplift for 1 restrained & 1 unrestrained slab
- all poured together using normal-density concrete

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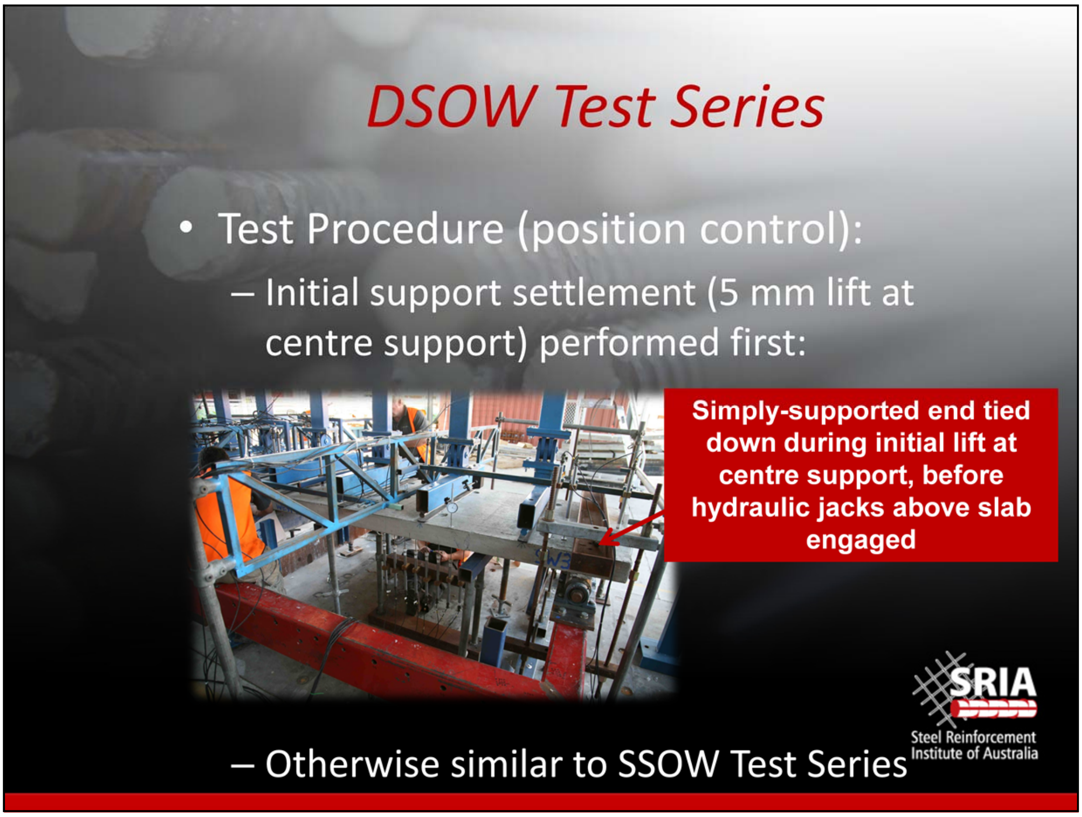
These details broadly describe the DSOW test series.

This shows a typical test set-up of one of the unrestrained DSOW slabs with its ends supported on the rollers, and with four line loads per span to simulate uniformly-distributed design loading.

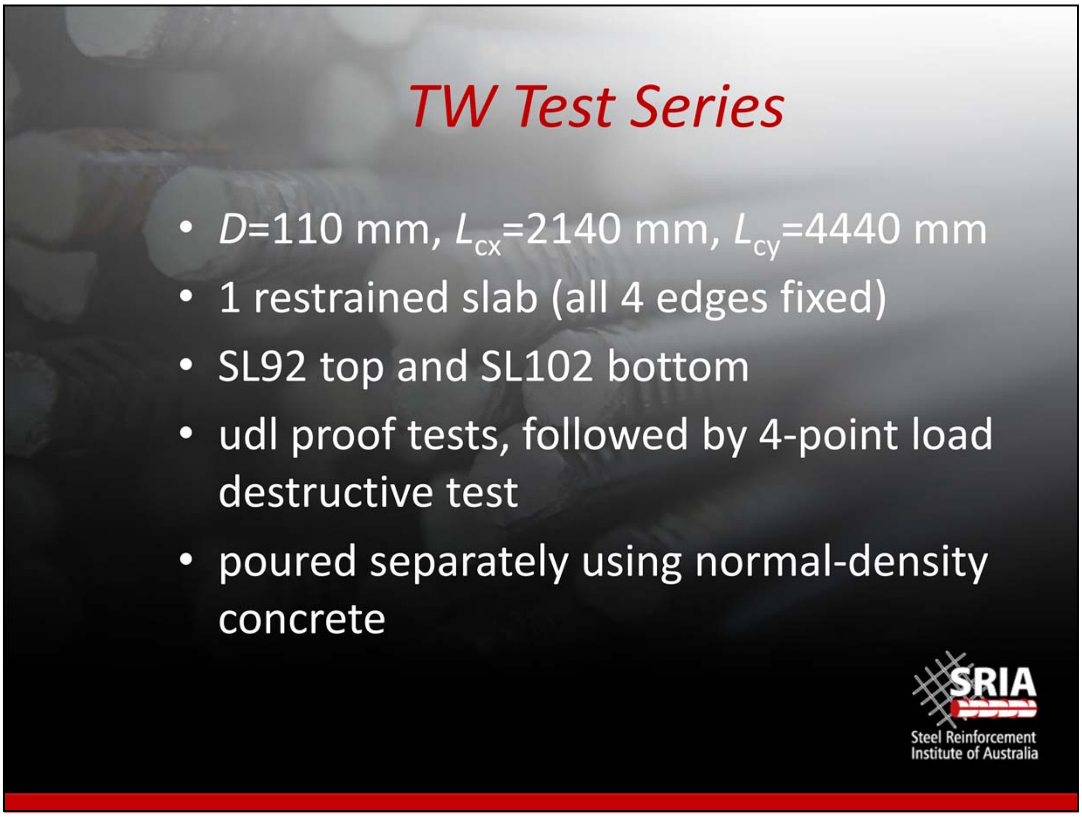
The four hydraulically-coupled jacks were operated in position control, suspended off the loading frame to avoid loading the slab with their dead load, and pinned at their tops to avoid longitudinally restraining the slab.

As shown by the small inset photograph, the central support comprised a guided steel assemblage which included load cells to be able to determine the central reaction at all stages of loading.



In the DSOW test with the slab ends simply-supported and in which the centre support was initially lifted up by 5 mm to simulate relative support settlement, this photograph shows how the ends had to be temporarily tied down.

After this severe loading event, the slab was subjected to a loading history similar in principle to that just described for the SSOW test series.

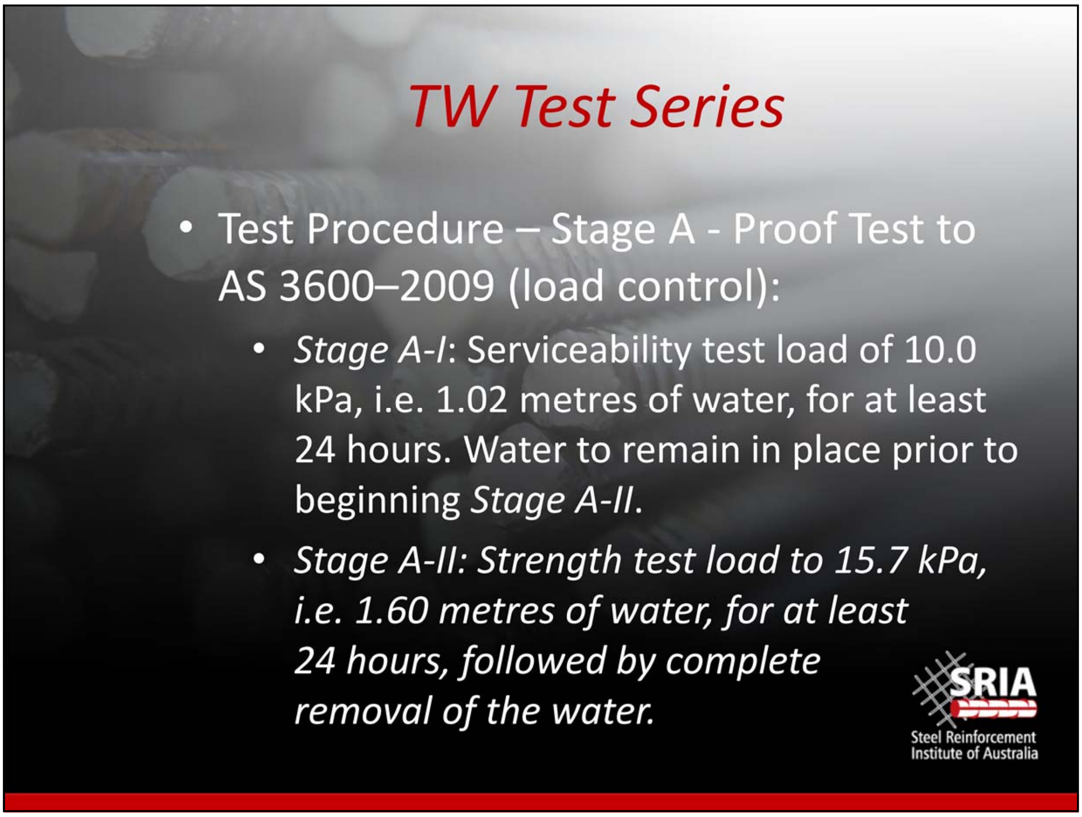


These details broadly describe the TW test series which only included one test slab.

It was subjected to two udl proof tests in accordance with Appendix B of AS 3600–2009, first for serviceability then for ultimate strength, followed by a 4-point load destructive test.

The slab was poured separately to the SSOW or DSOW slabs, but with nominally the same concrete.

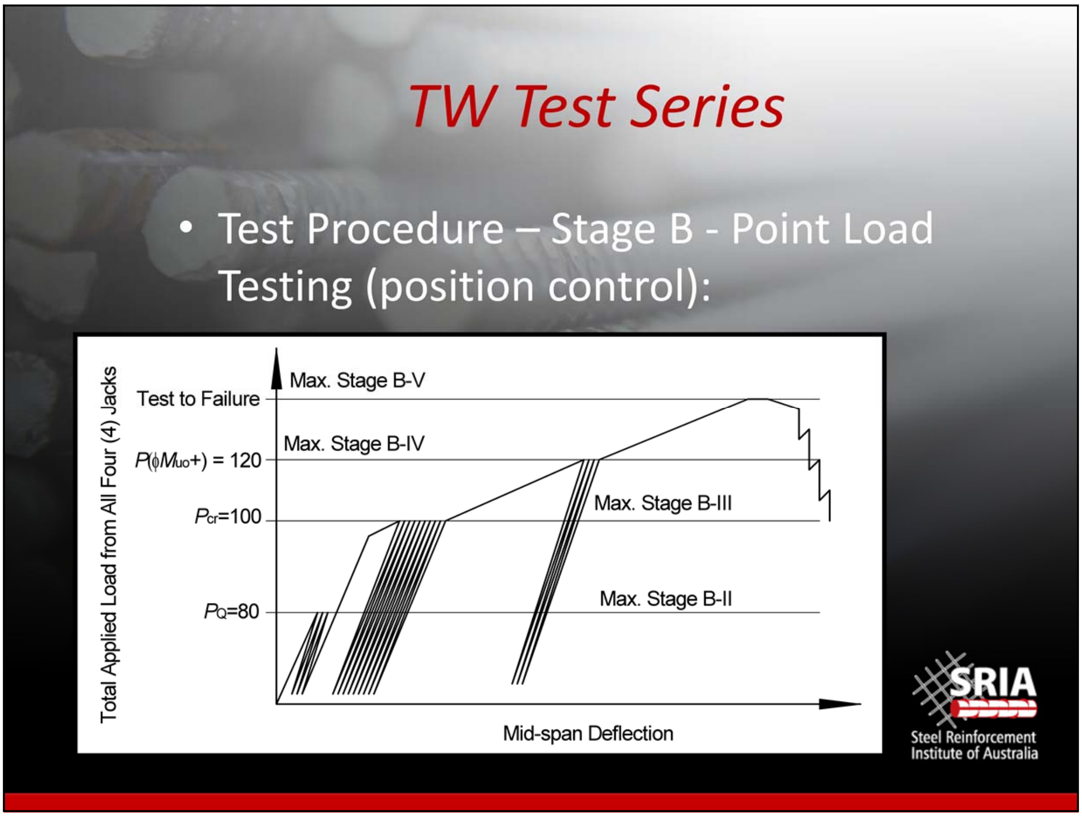
The test set-up involved loading the slab with water, with the temporary steel tank walls evident here. The small inset photograph shows one of the load cells used to record the vertical reactions during testing.



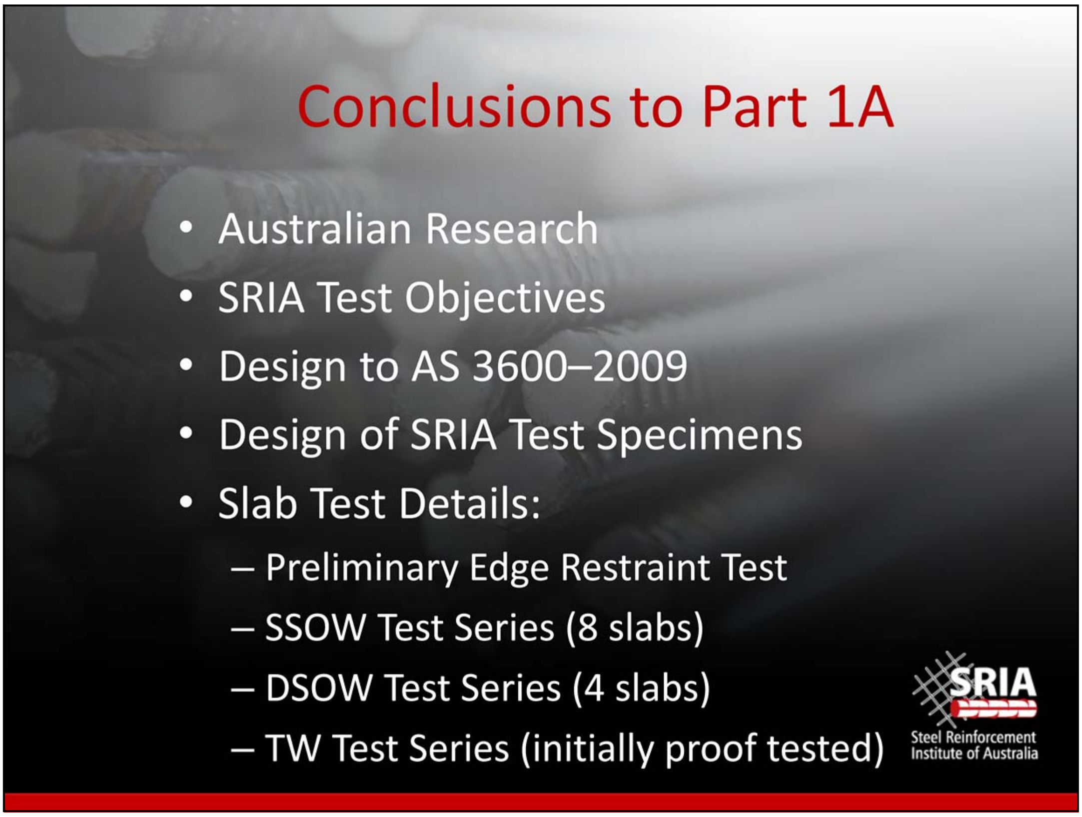
The test procedure of the Stage A proof test is explained here. The water represented a conservative (permanent) load, and therefore the test was performed in load control.

For Stage B, in order to fail the slab water could no longer be used, as the walls would have needed to be excessively high, and in any case the test needed to be performed in position control.

Four concentrated point loads were applied, each over a 200x200 mm square area, and symmetrically positioned about the centre of the slab.



The slab was then subjected to a loading history similar in principle to that described for the SSOW test series.



In conclusion:

Some of the Australian research into the behaviour of elevated beams and slabs with low ductility reinforcement performed prior to 2007 has been described, and how it was taken into account when designing the SRIA test slabs.

Because at the time the safety of this form of construction had been called into question, and as a result modifications were made to AS 3600, a primary objective was to test some slabs designed strictly in accordance with AS 3600.

Some of the design rules have been described, as have some aspects of the design of the test specimens. For example, all critical cross-sections were under-reinforced and therefore steel fracture was ultimately expected.

Finally, the details the 14 slab tests including the test rigs and rigorous test procedures were briefly explained.

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Question Time

SRIA's Class L Mesh Elevated Slab Tests

Scott Munter & Mark Patrick

Part 1A – Objectives, Design & Details