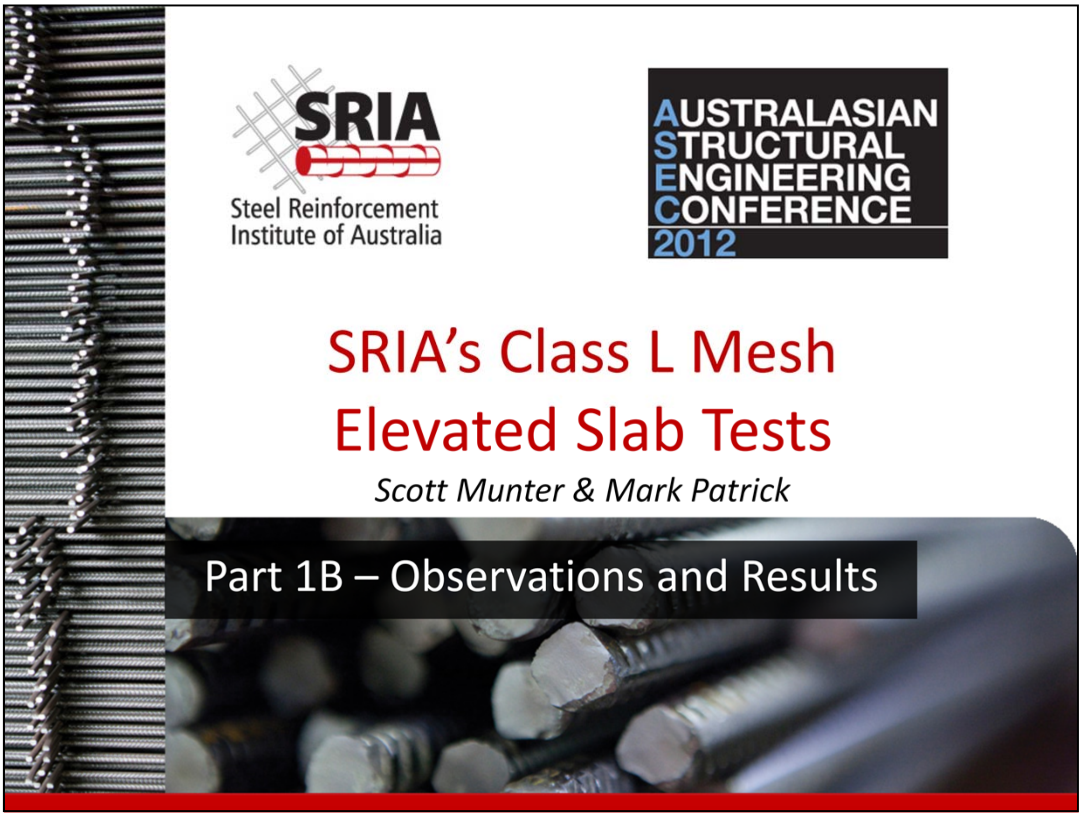
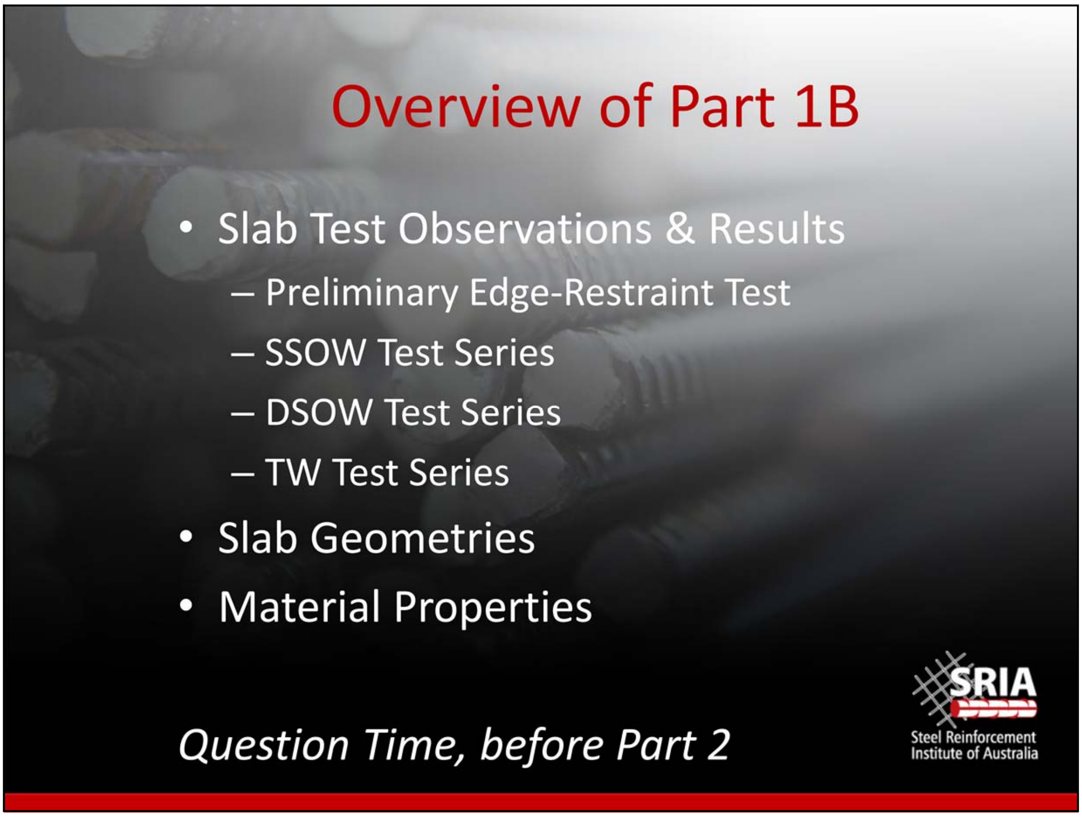
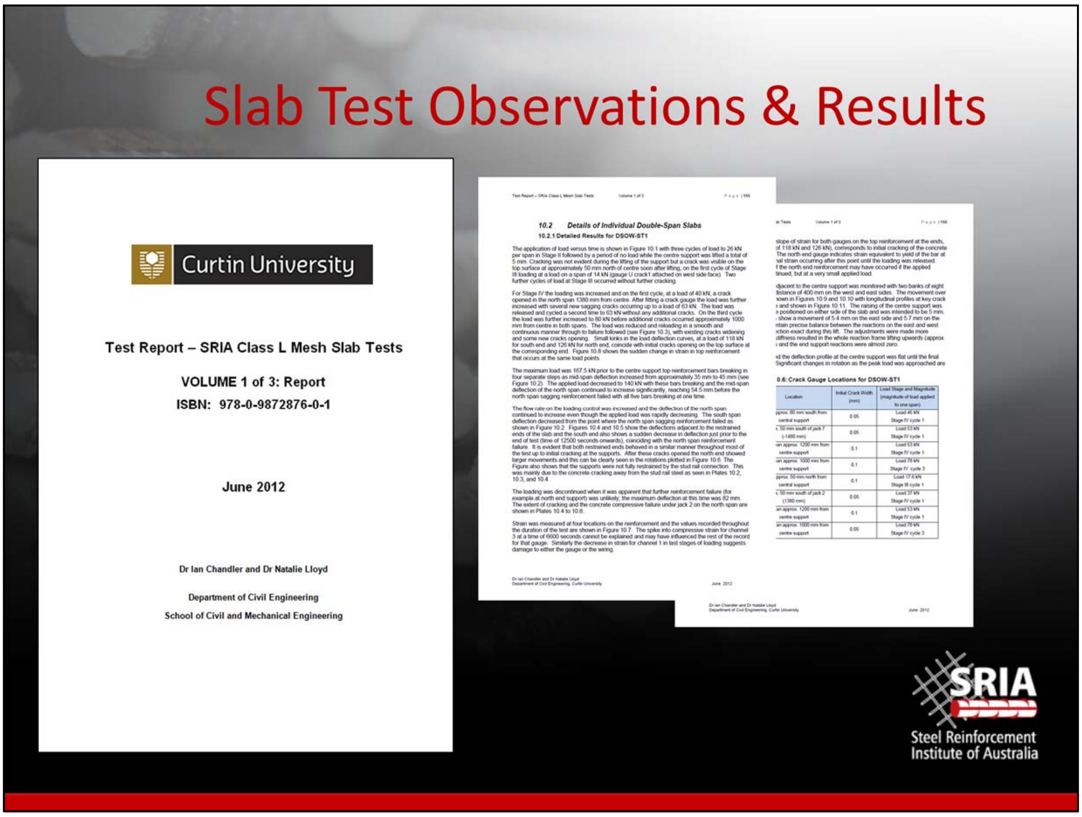


In this Part 1B presentation, the test Observations and Results will be briefly described.



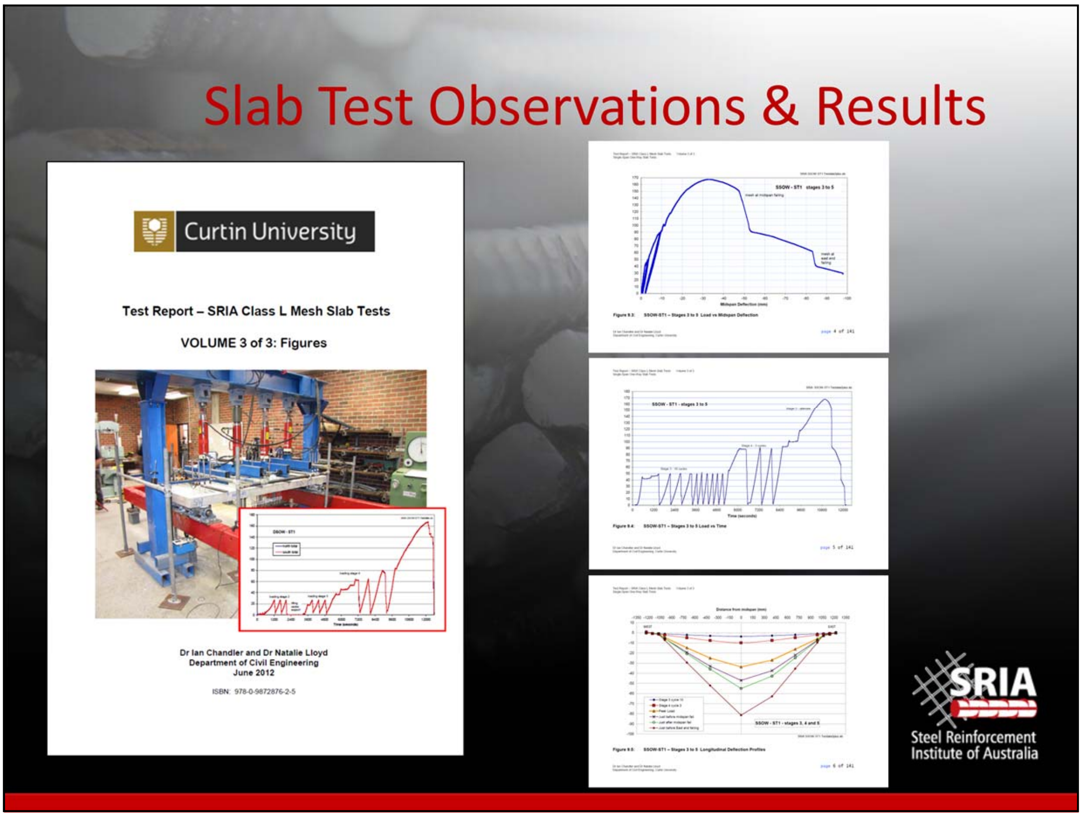
The presentation will cover the Preliminary Edge-Restraint Test, as well as the SSOW, DSOW and TW test series.

Important information about slab geometries and material properties will be briefly described.

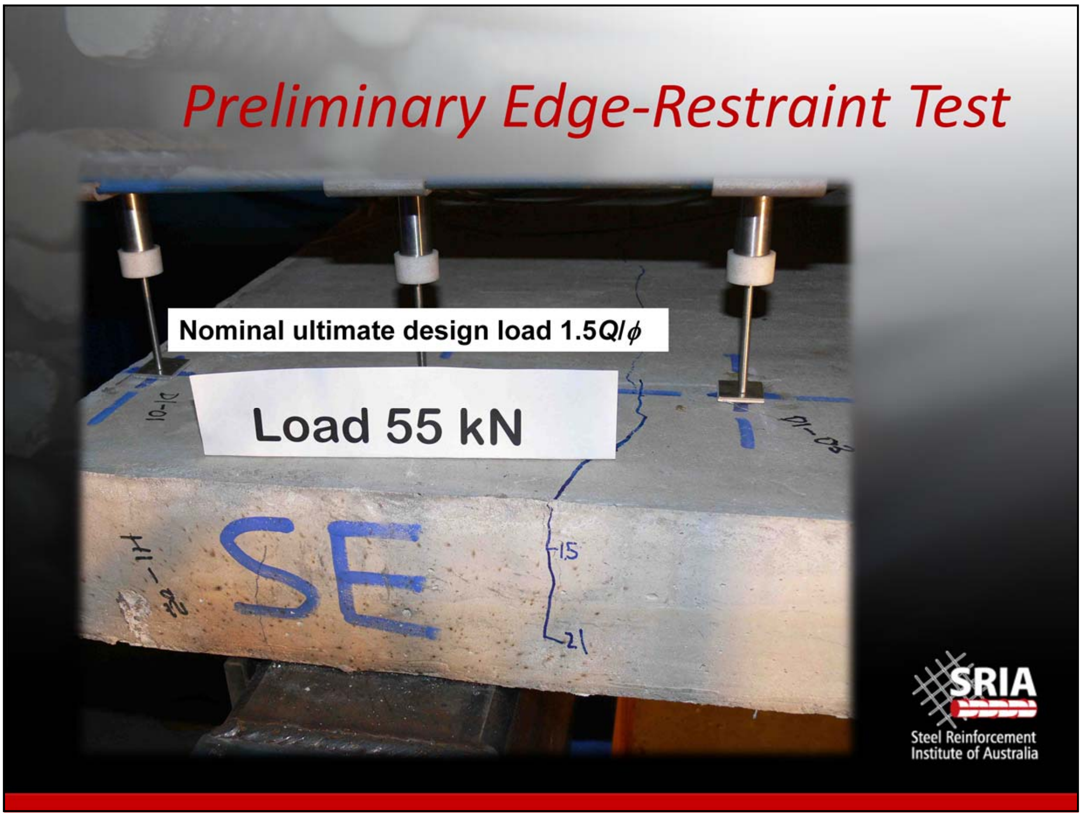


Detailed written accounts of the test observations and results are contained in Volume 1 of the Curtin Test Report.

The written accounts in Volume 1 directly refer to plates or photographs contained in Volume 2.



Similarly, they refer to specific figures contained in Volume 3 of the Curtin Test Report.

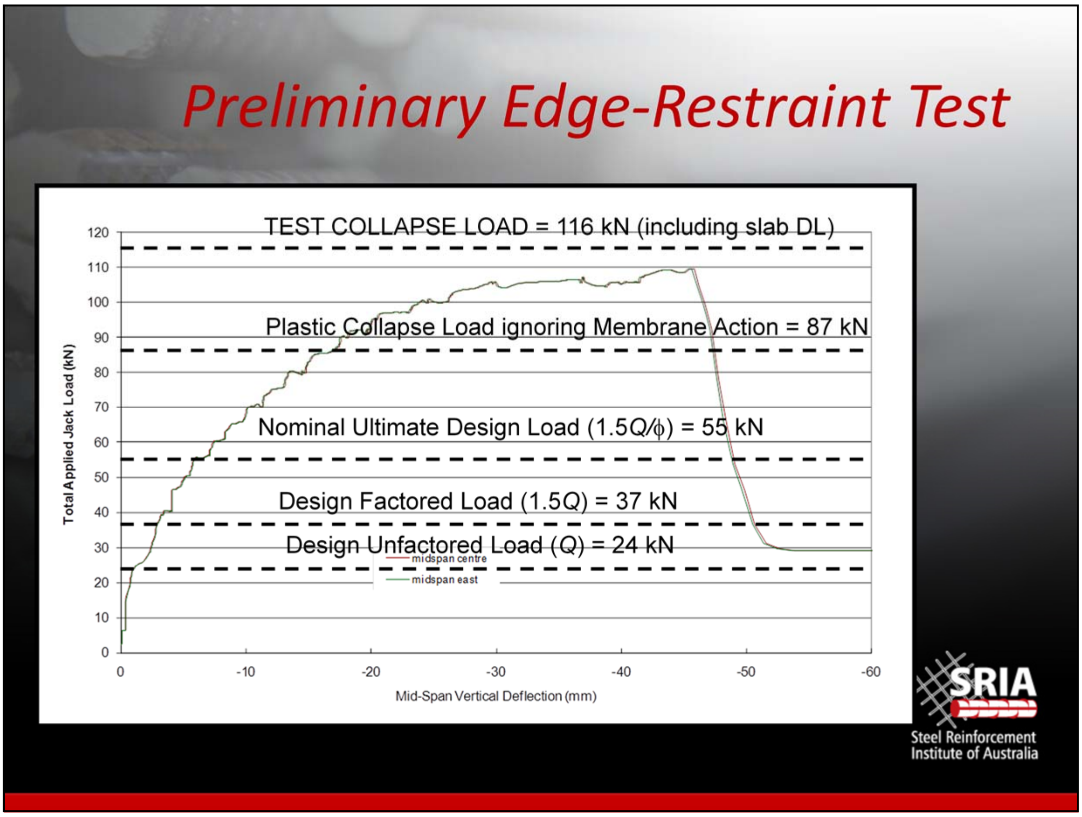


It has been mentioned that the Preliminary Edge-Restraint Test slab supported a maximum applied load of 116 kN before the mid-span bars necked and subsequently fractured.

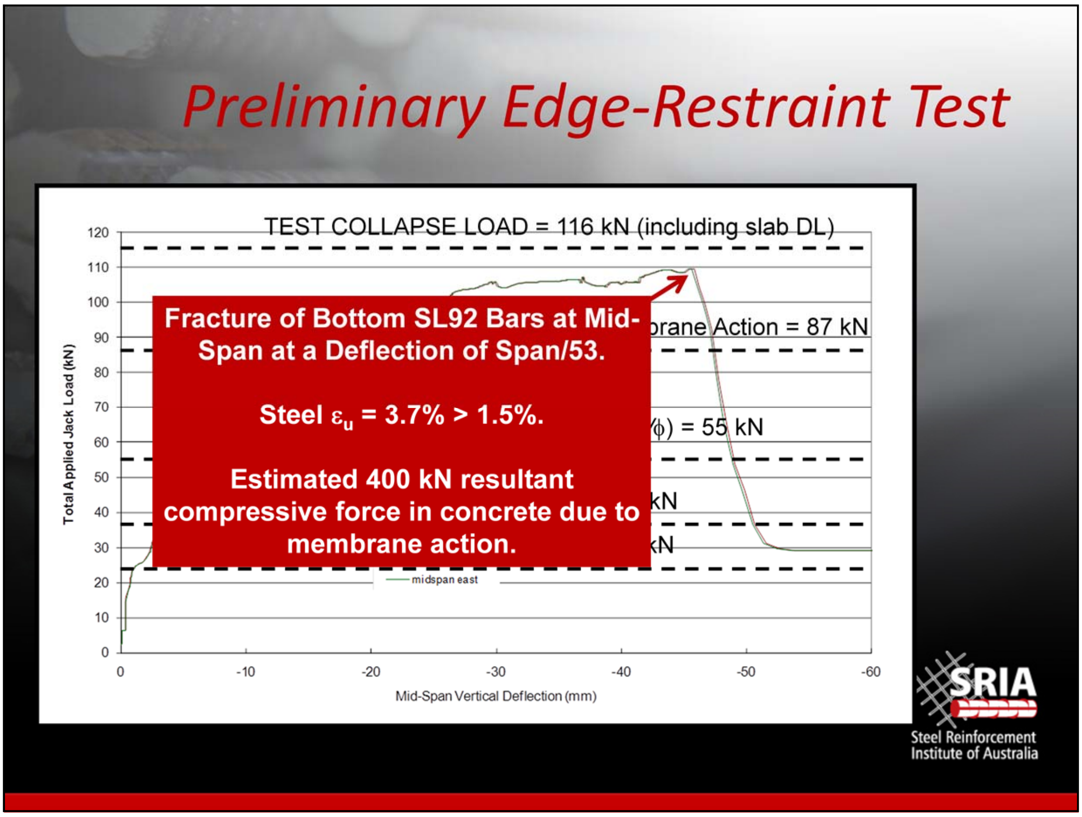
The photograph shows the condition of a restrained end-support region at the nominal ultimate design load of 1.5 times the design live load, Q, divided by the strength reduction factor, ϕ, equal to 0.64.

It is very clear from the photograph that the region was only lightly cracked, and otherwise in perfect condition despite the slab being loaded well above the design ultimate load calculated using AS 3600–2009 based on conservative elastic analysis.

The positive moment region was equally only finely cracked and in excellent condition.



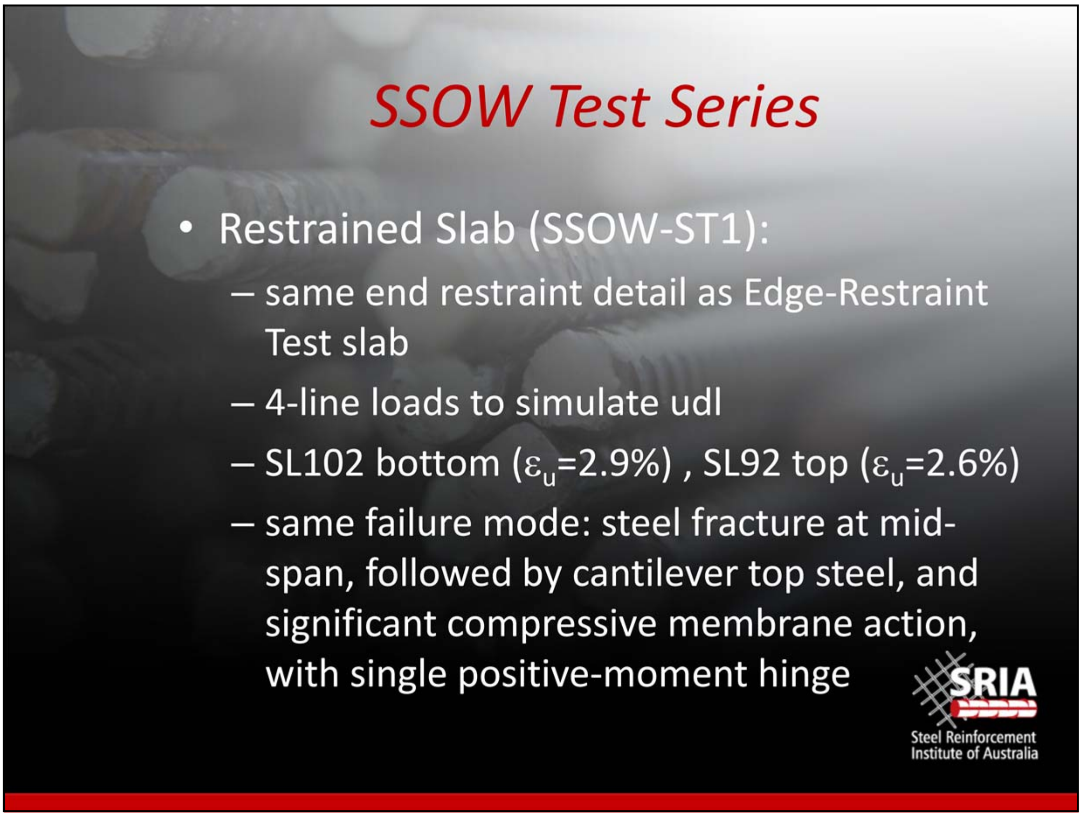
The load-deflection curve for the test is revealed here, and it shows that the mid-span deflection of the slab at 55 kN applied load was only about 6 mm, or span/400, implying that it could have still been serviceable depending on the specific performance requirements.



Fracture of the bottom SL92 bars occurred at a mid-span deflection of span/53.

The average uniform strain of these bars was 3.7%, well above the minimum code requirement, but nevertheless, representative of Ductility Class L mesh.

When the positive hinge failed at mid-span, the 400 kN compressive force in the slab would have completely dissipated, and therefore it's not surprising that the load dropped off suddenly, reverting to two cantilevers under essentially flexural action. Up until this stage, the slab performed entirely satisfactorily, and the design to AS 3600 was clearly very conservative.

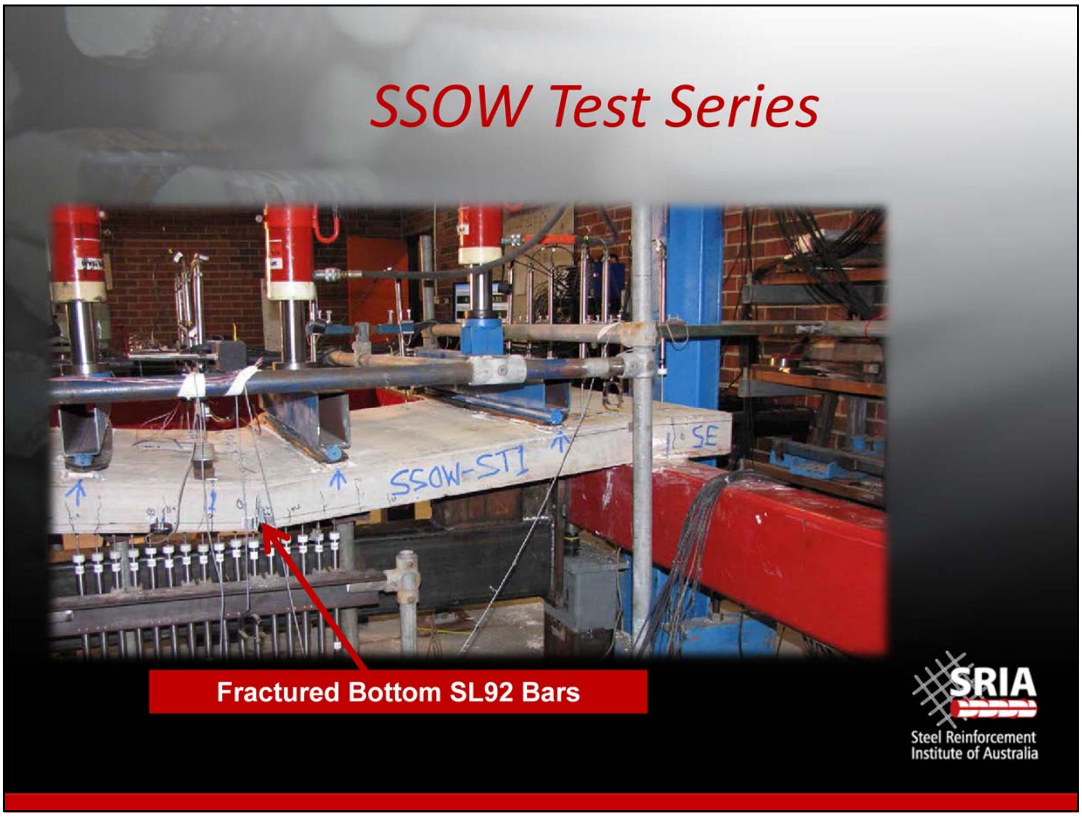


The first of the SSOW slabs (SSOW-ST1) had the same end restraint detail as the Edge-Restraint Test slab.

However, in this test uniformly-distributed loading conditions were simulated.

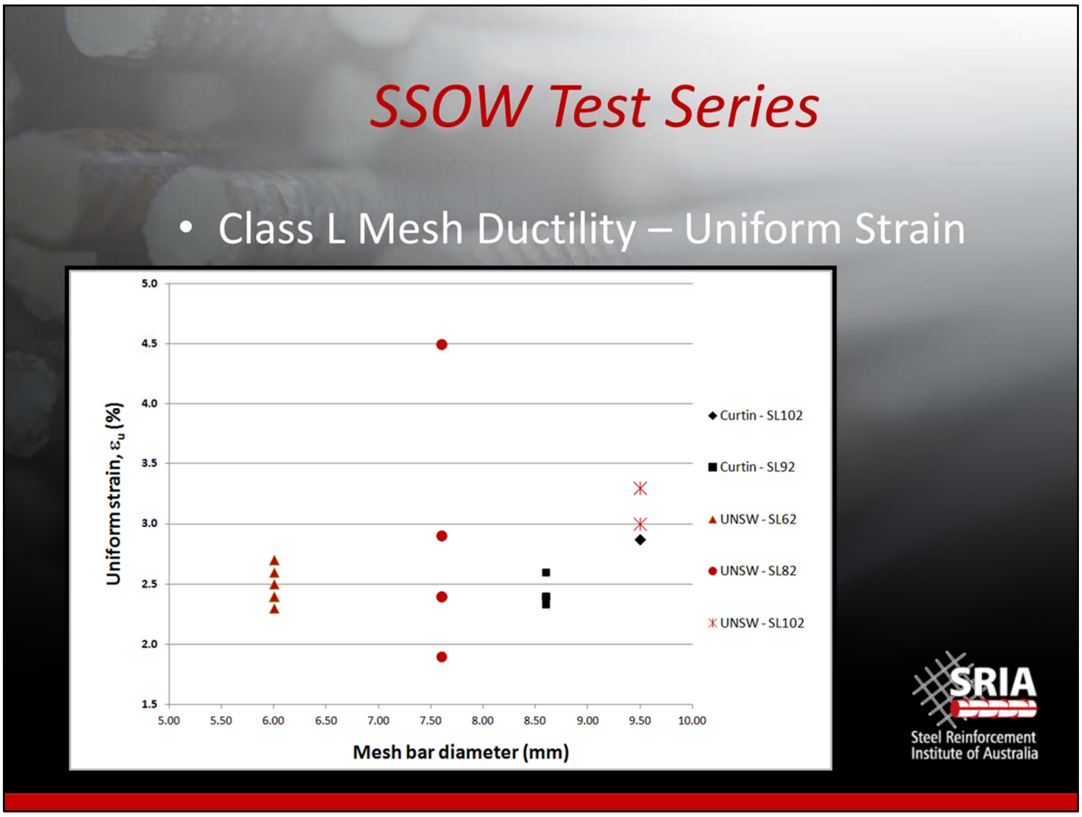
The top and bottom meshes both had average uniform strains of less than 3%.

The same failure mode was exhibited as for the Edge-Restraint Test slab, and the behaviour was effectively identical.

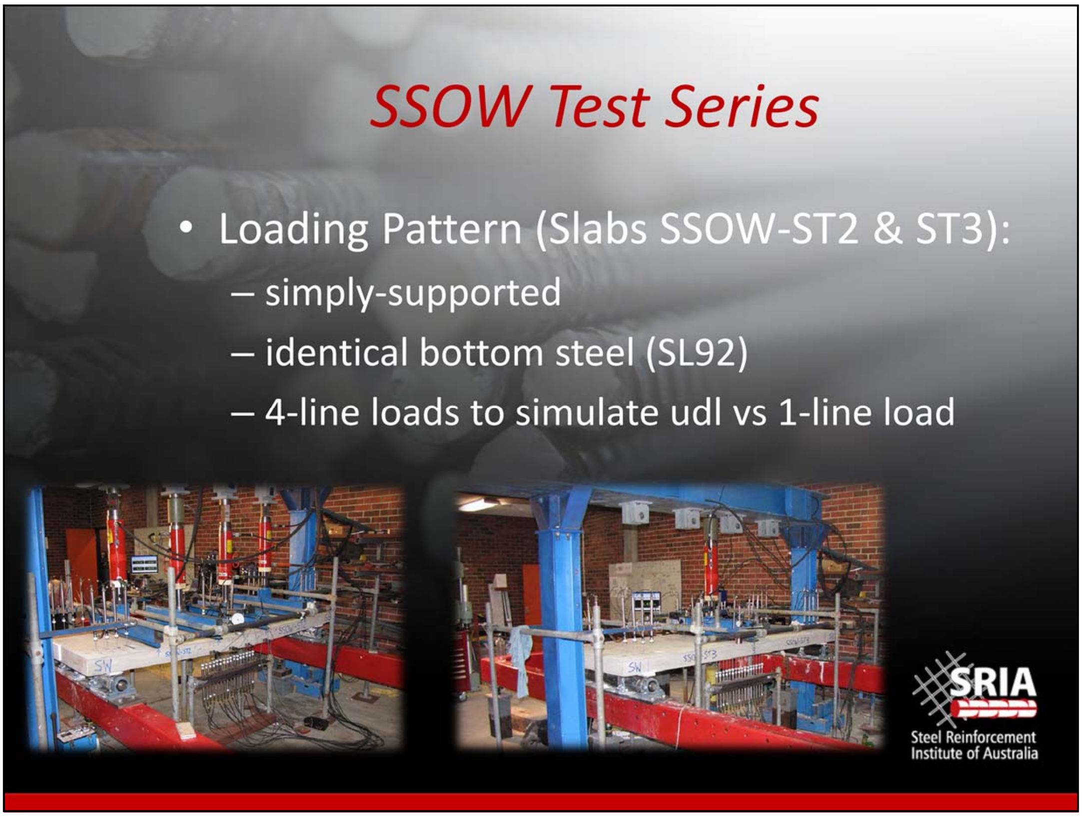


This shows the condition of the slab after the main bars of the bottom mesh had fractured.

Notice the additional tubular steel beam under the slab, tying together adjacent sides of the ring beam and balancing the high resultant compressive force that developed in the slab before the bars broke.



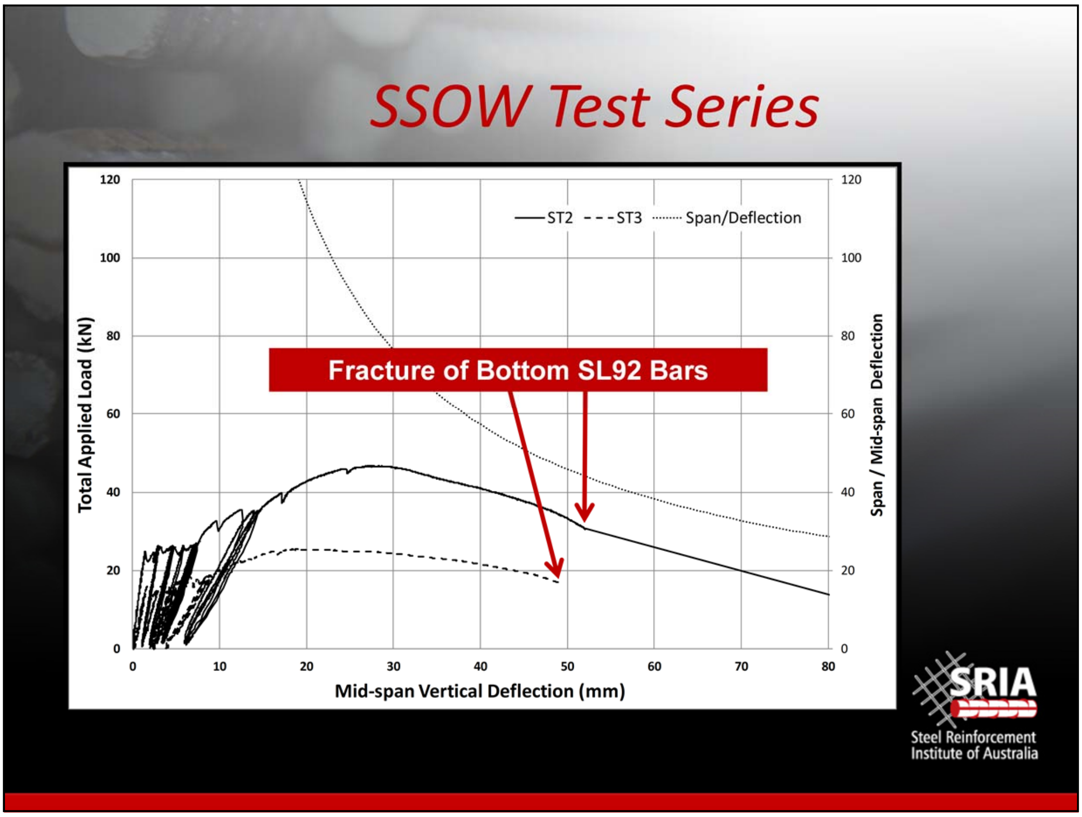
Returning to some of the Australian Research performed prior to conducting the SRIA tests, this graph of uniform strain plotted against mesh bar diameter shows that the meshes used in SRIA's Curtin University slab tests had similar average uniform strains to those used in the UNSW slab tests.



All of the rest of the SSOW slabs were tested in the simply-supported condition.

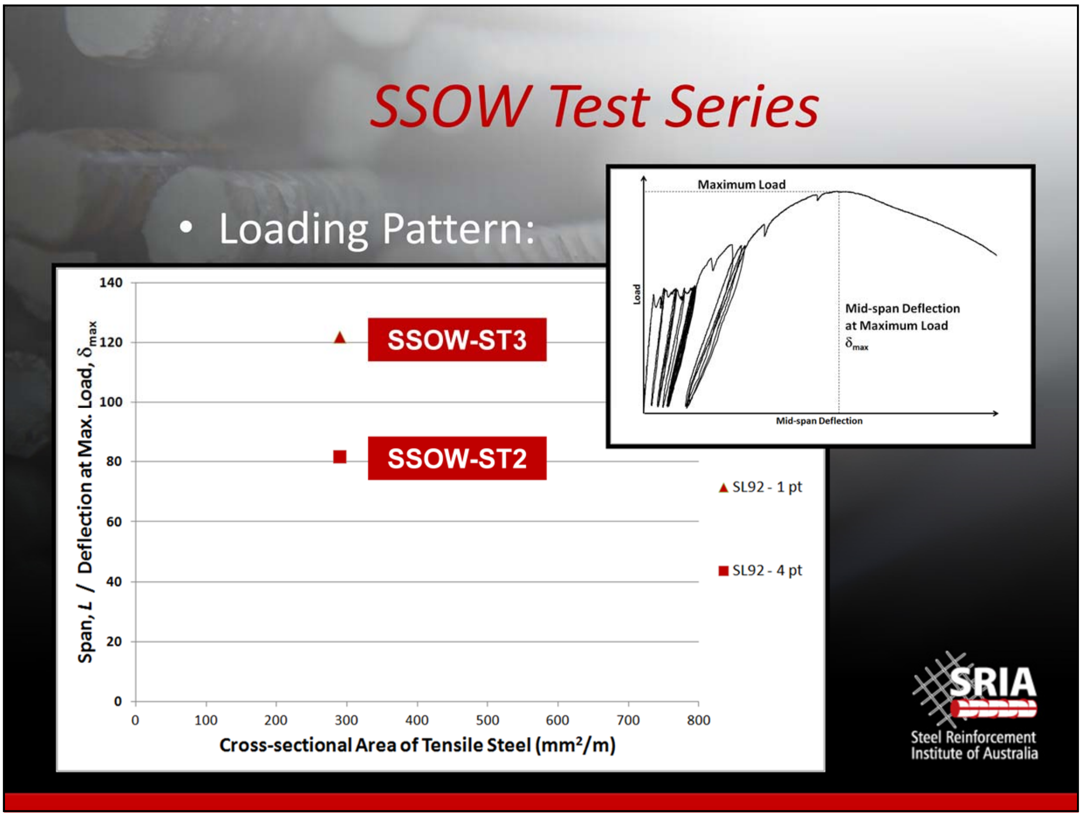
The two slabs SSOW-ST2 and ST3, seen under test in the two photographs, were nominally identical with SL92 bottom mesh that had very similar average tensile properties.

The primary difference between the two tests was the way the slabs were loaded, either with 4 line loads or with one at mid-span.



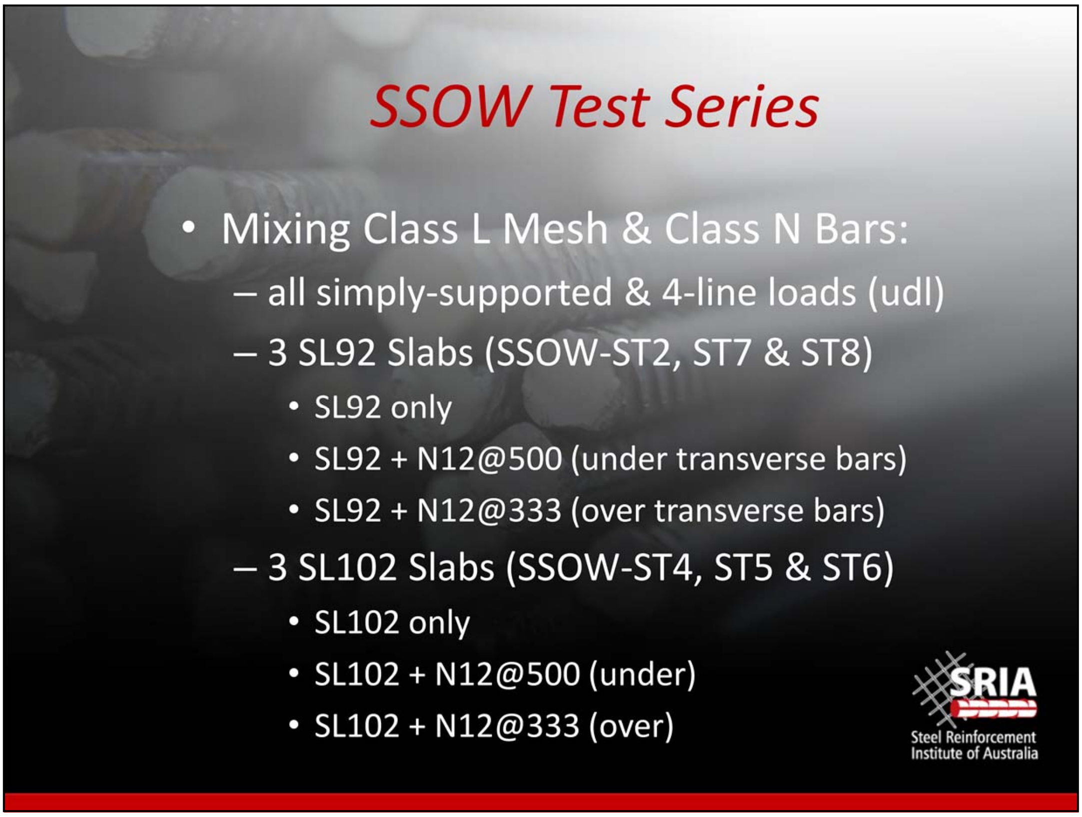
These are the load-deflection curves for the slabs ST2 (4 line loads) and ST3 (1 line load, shown dashed).

Although the bottom main bars fractured in the two tests at similar mid-span vertical deflections of about 50 mm or span/46, looking at the curves carefully it can be seen that the slab loaded only in the middle reached its peak load at a much smaller mid-span deflection.



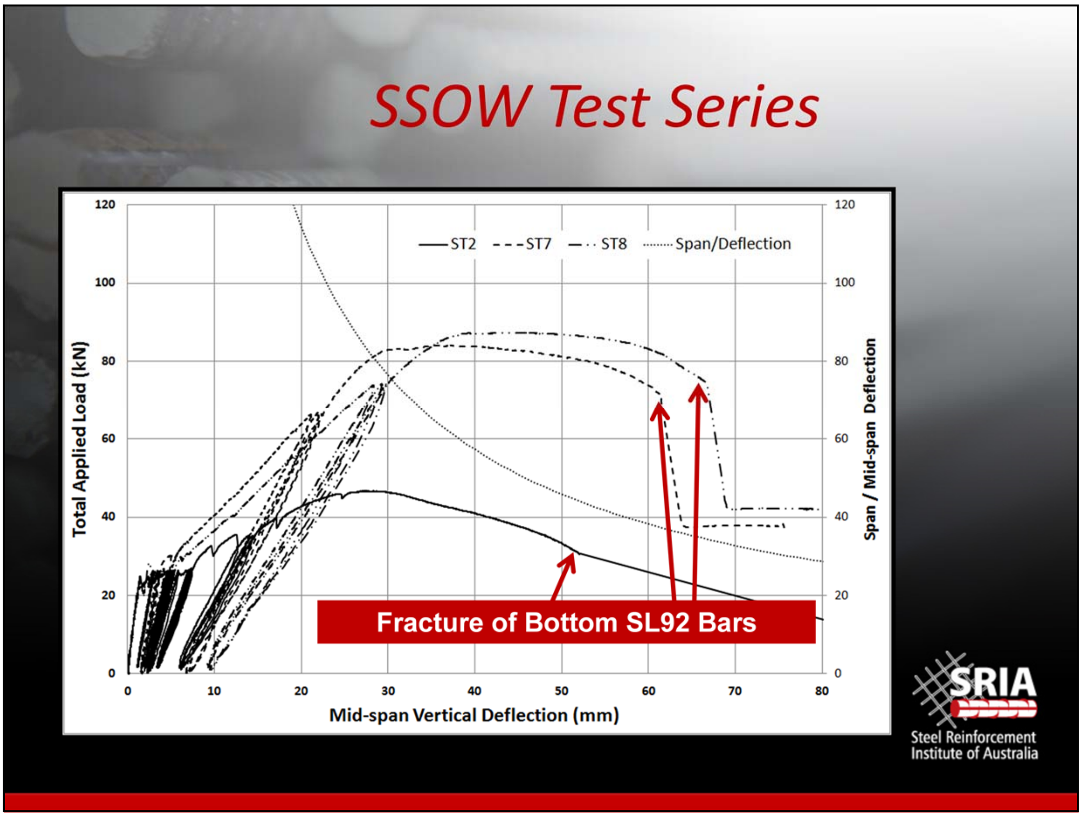
This is expected because although the maximum bending moment reached in each test would have been almost identical, the uniformly-loaded slab SSOW-ST2 which reached its maximum at span/80 had a much more rounded bending moment diagram. Therefore there were more flexural cracks, and correspondingly more deflection.

It follows that the loading arrangement can significantly affect the maximum deflection at peak load, although this is not a design criterion in AS 3600, or indeed in the Building Code of Australia.



Six of the SSOW slabs were used to examine the effects of mixing different-sized Class L meshes with different amounts of Class N bar and at slightly different depths.

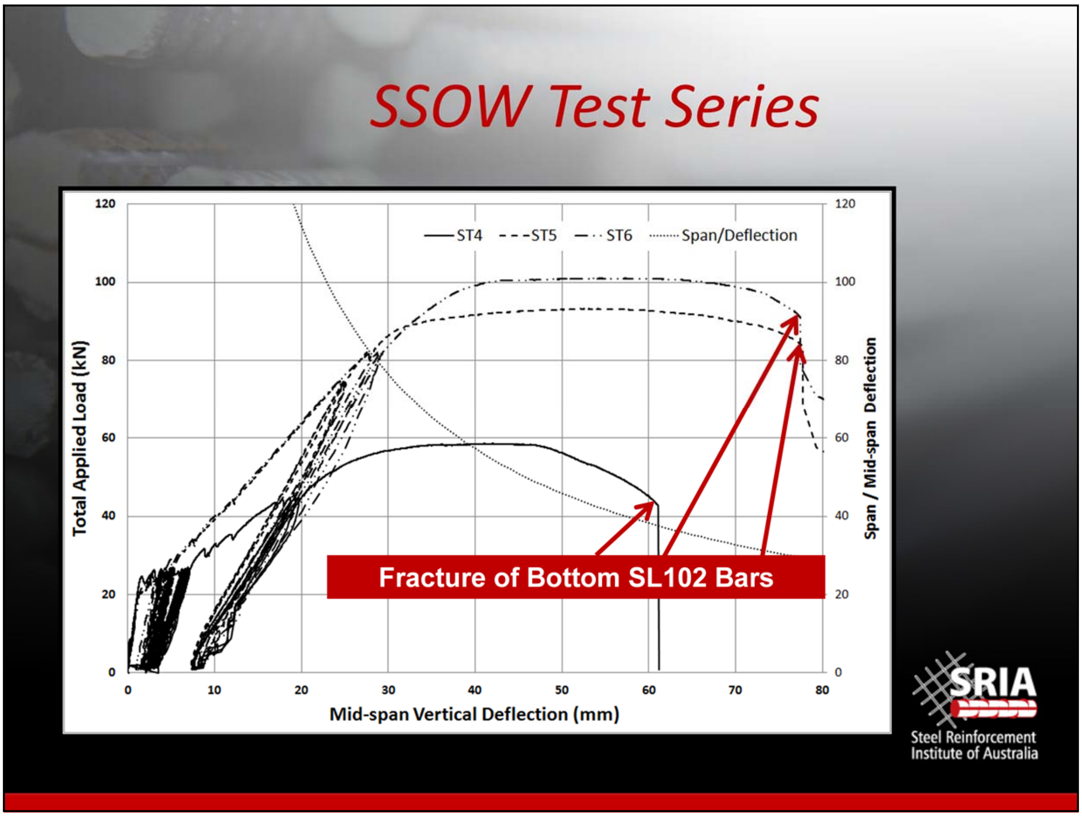
As shown previously, all of the slabs' critical sections were under-reinforced, and also, all three slabs were effectively uniformly loaded.



Here are the three load-deflection curves for the slabs with SL92 bottom mesh.

The bottom solid curve is for the slab which only had mesh, and the successively higher curves are with 2 and 3 N bars added per metre width, respectively.

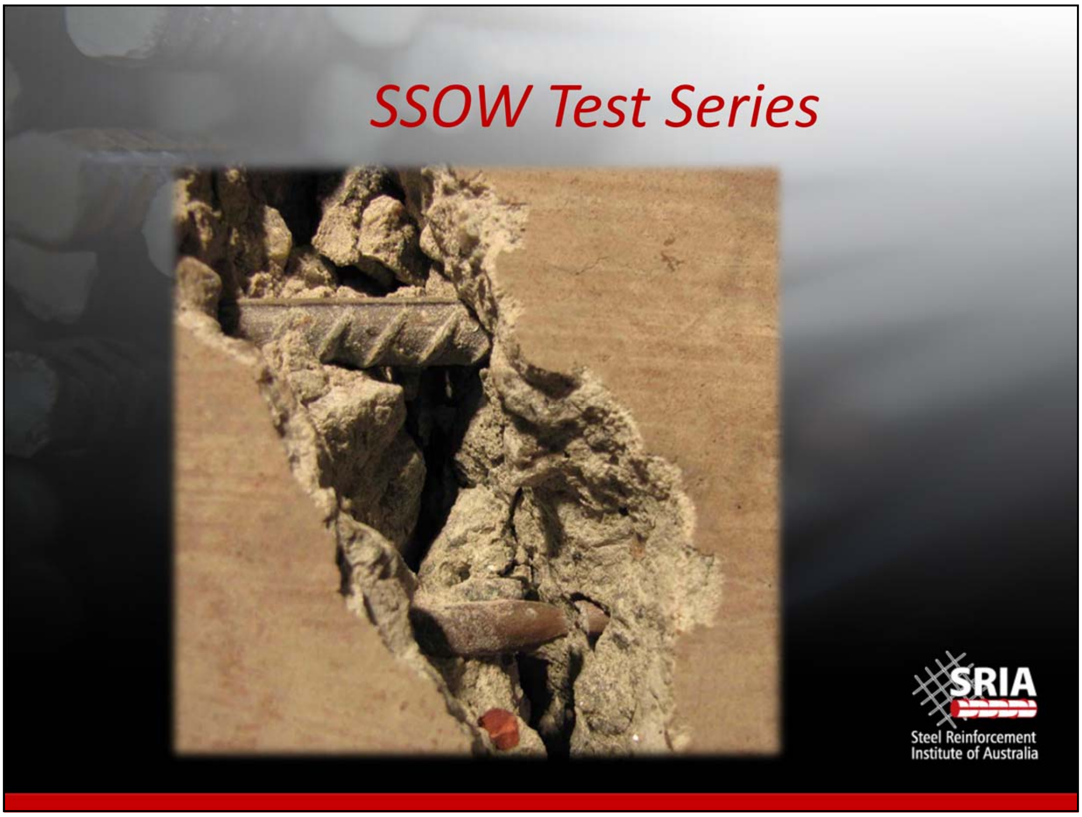
As predicted, the main mesh bars eventually fractured in each slab, in each case at a much larger mid-span deflection than that corresponding to peak load.



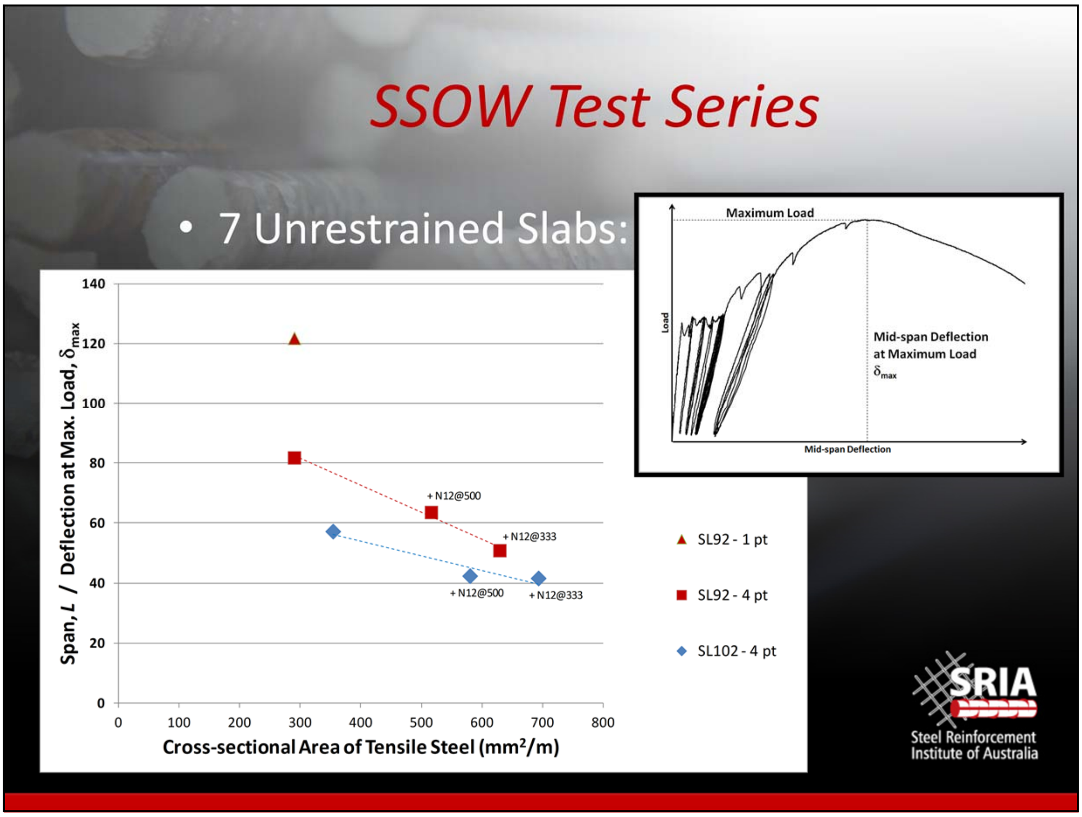
Similarly, these are the three load-deflection curves for the slabs with SL102 bottom mesh.

Again, the bottom solid curve is for the slab which only had mesh, and the successively higher curves are with 2 and 3 Class N bars added per metre width, respectively.

The main bars eventually fractured again at much larger mid-span deflections than those corresponding to peak load.



This photograph shows where a main mesh bar has necked and fractured, while the N12 bar nearby would have yielded but has not fractured. However, had the test been continued and the deflection progressively increased, the N12 bars could have also been broken.

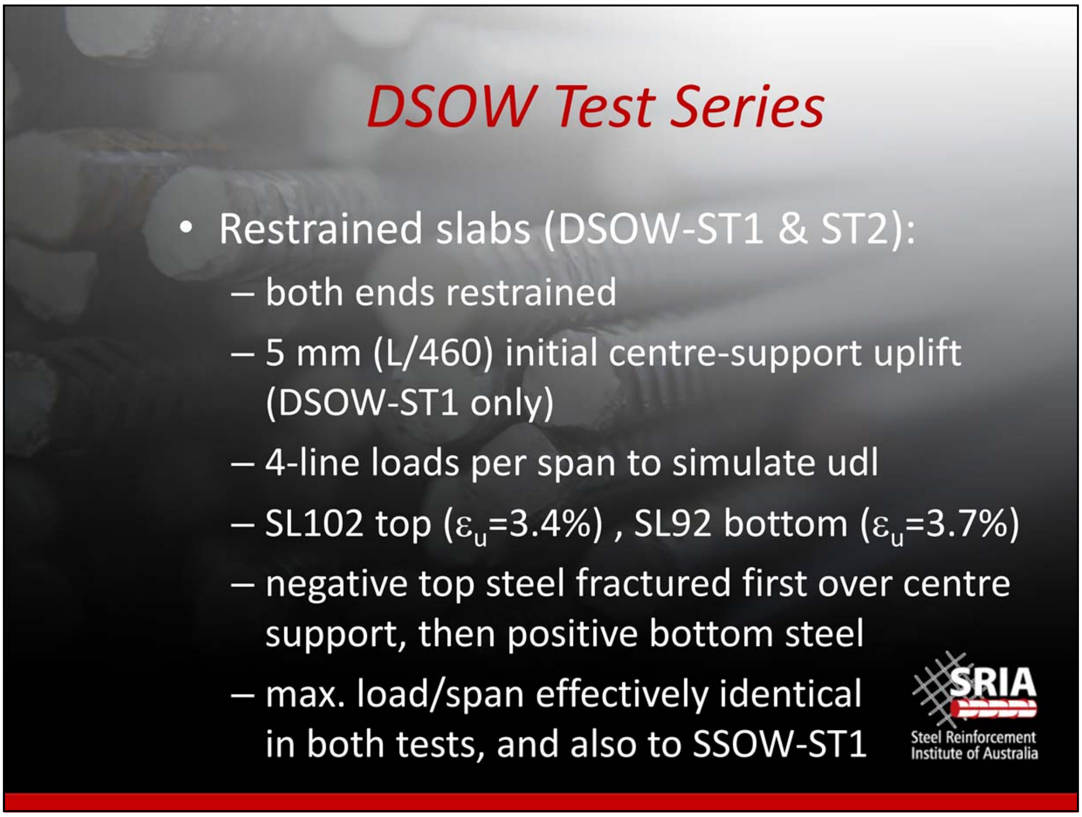


Looking at the results of all 7 unrestrained SSOW slabs, their mid-span deflection at maximum load can be compared.

As before, the vertical axis is the span divided by the deflection at maximum load, and the horizontal axis is the total cross-sectional area of the bottom tensile steel, comprising either mesh alone, or mesh with N12 bars tied above or below it.

The top data point is for the SL92 slab acted on by a mid-span line load, which deflected the least at maximum load.

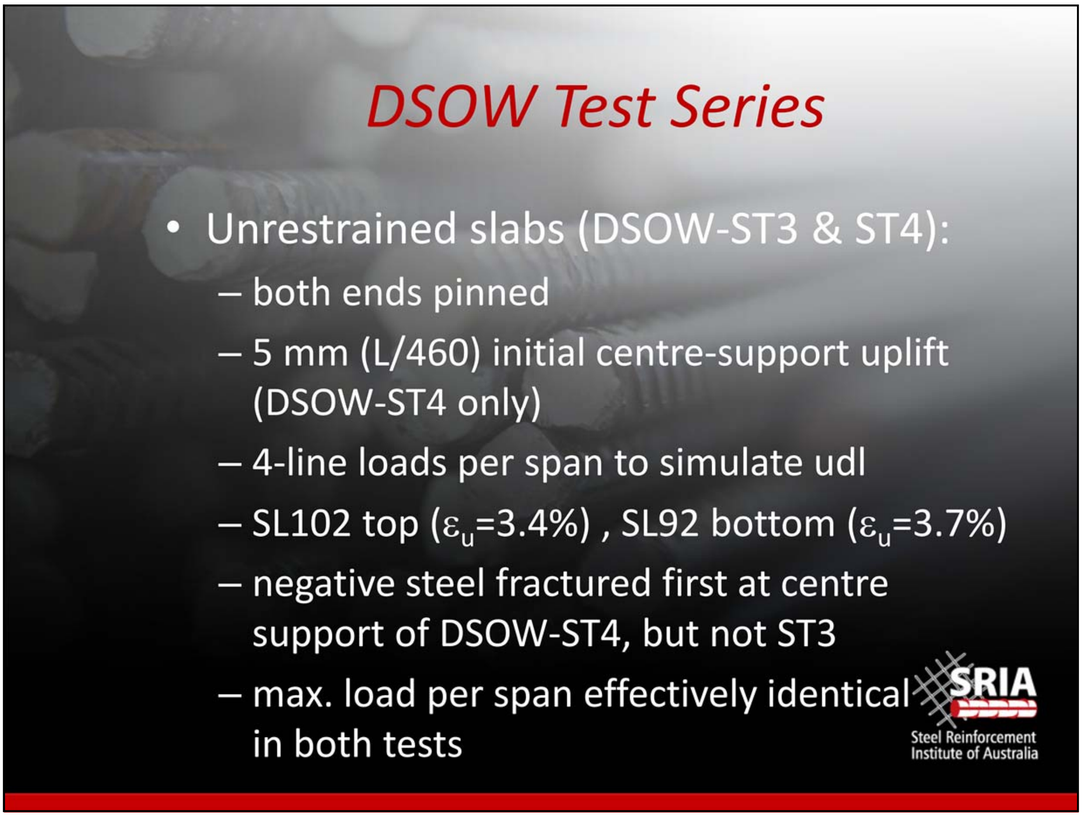
It can be inferred from the other two groups of three data points for each mesh size, that steel area could have influenced the deflection at maximum load.



Regarding the DSOW Test Series, two of the slabs (DSOW-ST1 and ST2) had both of their ends restrained. The first of these slabs was subjected to the initial 5 mm uplift, but otherwise the tests and the slabs were identical to each other.

The average uniform strains of the main bars of the SL102 and SL92 meshes were similar.

Despite the large support settlement, which based on elastic theory could have induced peak bending moments in excess of both the positive and negative design ultimate moment capacities, both slabs failed the same way, with the top steel bars over the centre support breaking first, followed subsequently by the bottom steel under an inner loading point. Importantly, the maximum loads reached in the two tests were effectively identical.



The other two DSOW slabs (ST3 and ST4) had both of their ends unrestrained. The latter of these slabs was subjected to the initial 5 mm uplift, but otherwise the tests and the slabs were identical to each other.

The SL102 and SL92 meshes were very similar to the other DSOW slabs.

The slab DSOW-ST4 subjected to support settlement again failed when the top steel bars over the centre support broke, but for ST3 the bottom steel broke first under one of the inner loading point near an end. Nevertheless, the maximum loads reached in the two tests were effectively identical.

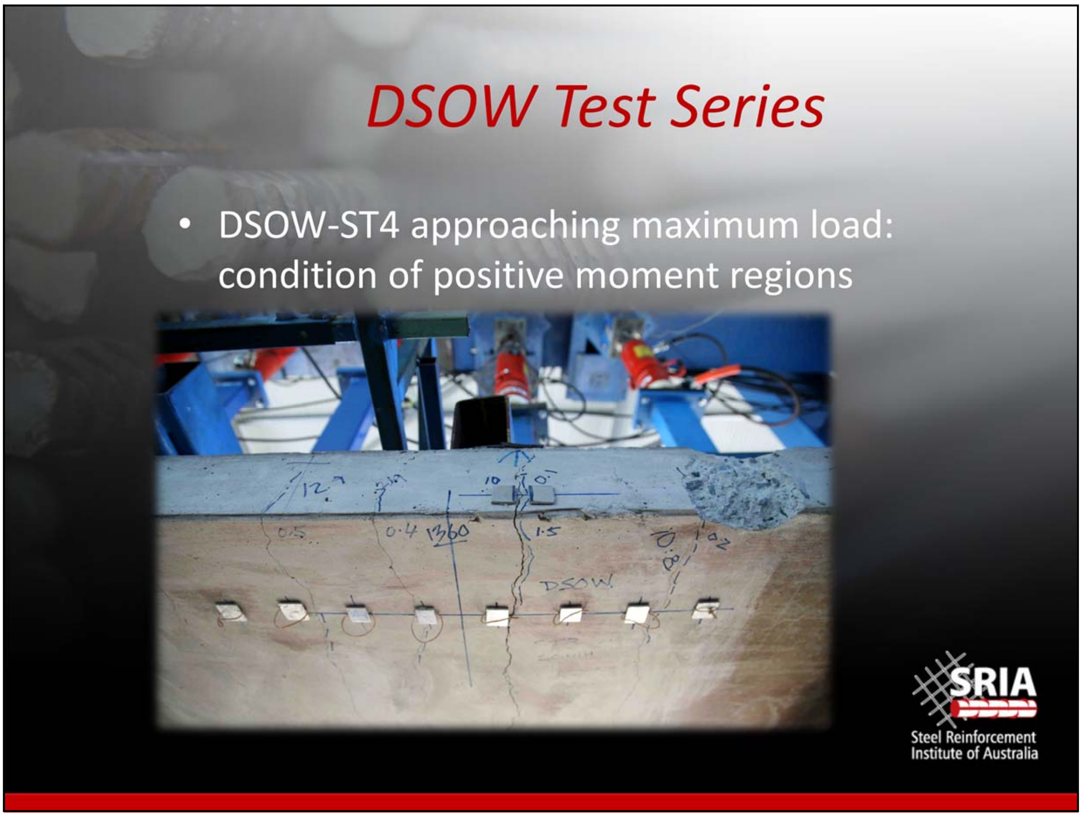
In 2008 the UNSW tested five double-span slabs for the effects of support-settlement with mesh of similar ductility to that in the SRIA tests, and they concluded that "*The imposed support settlements did not affect the strength of the slabs and the reinforcement was able to accommodate the settlements without compromising the strength.*"

DSOW Test Series

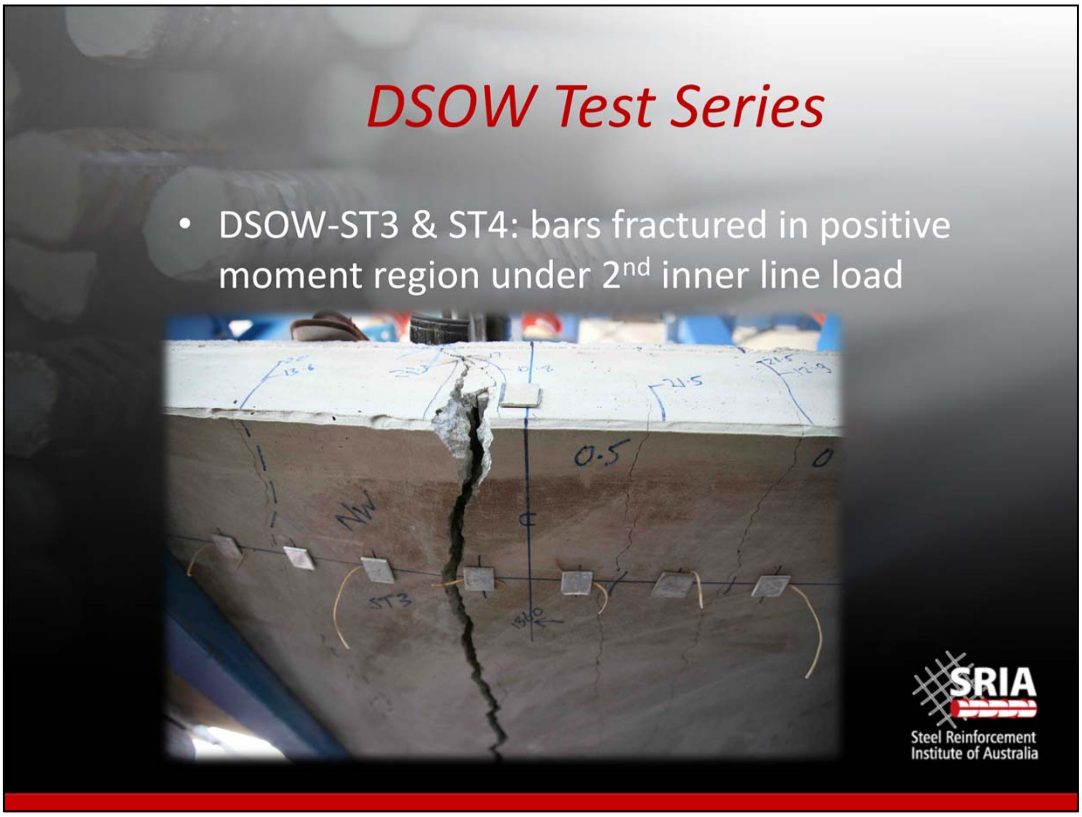
- DSOW-ST4 approaching maximum load:

This photograph shows the deflected shape of the slab with the unrestrained ends approaching maximum load before the mesh fractured over the central support.

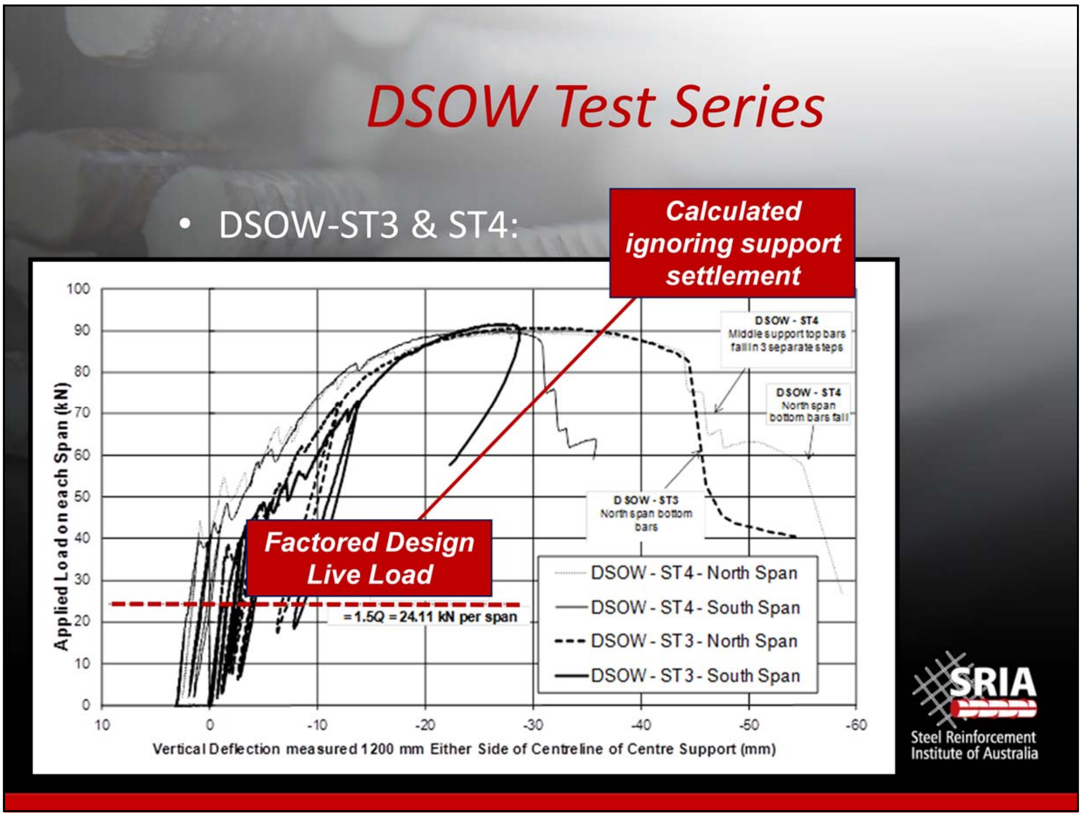
The major crack over the central support can be seen here, and the small inset photograph is a close-up of the fractured main mesh bars.



This photograph shows the condition of the critical positive moment region while approaching maximum load, and it’s clear that the major flexural crack was much narrower here.



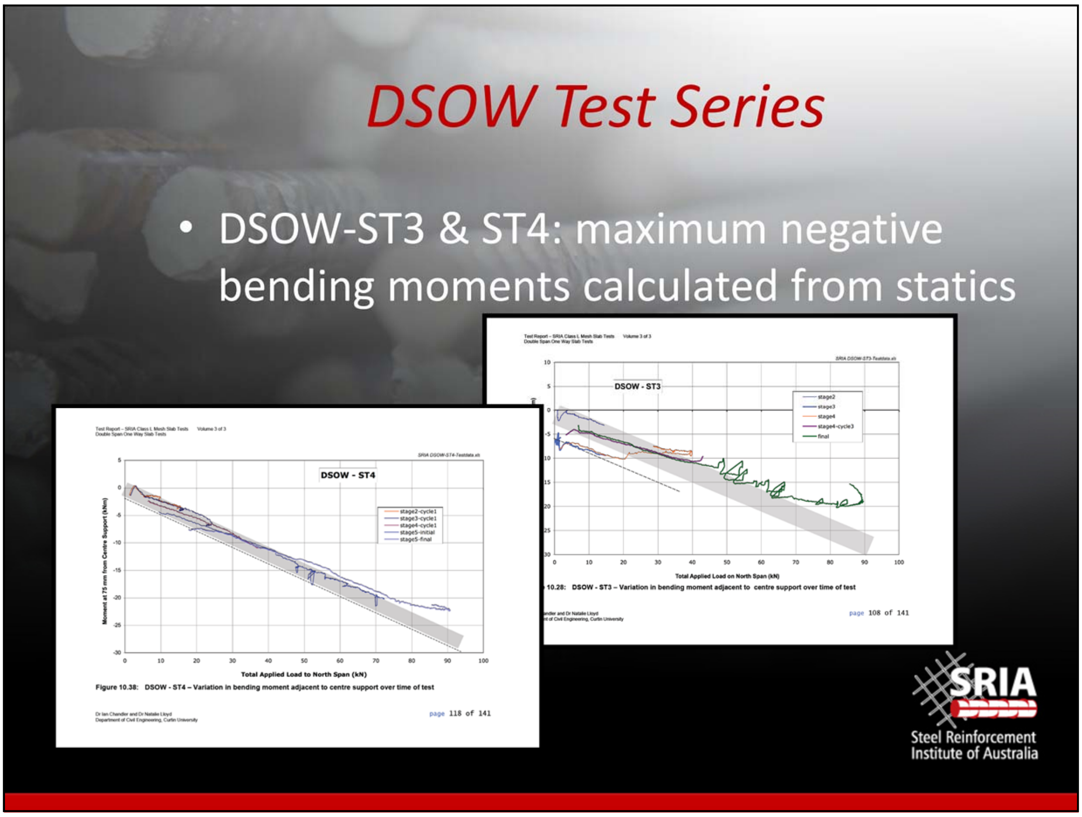
This shows how the positive moment regions of both DSOW-ST3 and ST4 both failed with bar fracture.



The load-deflection curves for both of these slabs are shown together here.

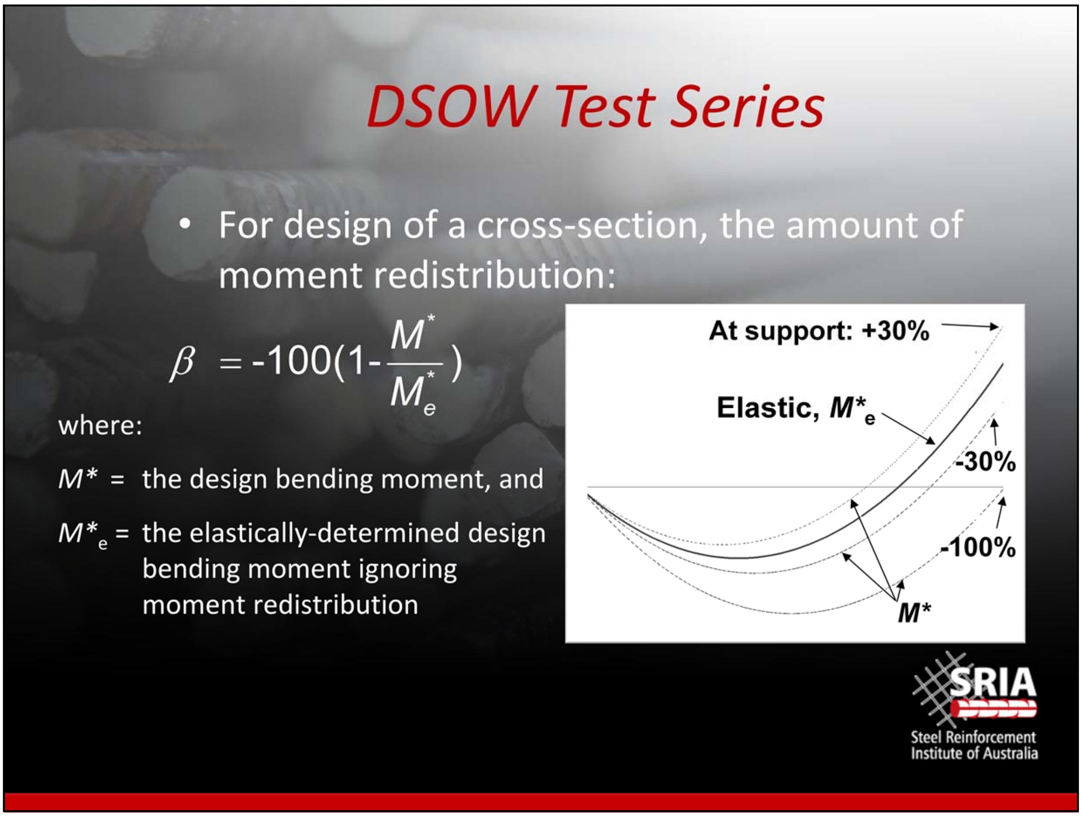
It can be seen that they reached almost identical peak loads before bar necking and subsequent fracture precipitated the collapse mechanisms just described.

The dashed horizontal line shows the factored design live load of 1.5*Q* based on elastic design to AS 3600–2009, ignoring the effects of support settlement in the case of DSOW-ST4. The conservativeness of the design is apparent, as is the apparent ability of DSOW-ST4 to accommodate moment redistribution due to the initial support movement.

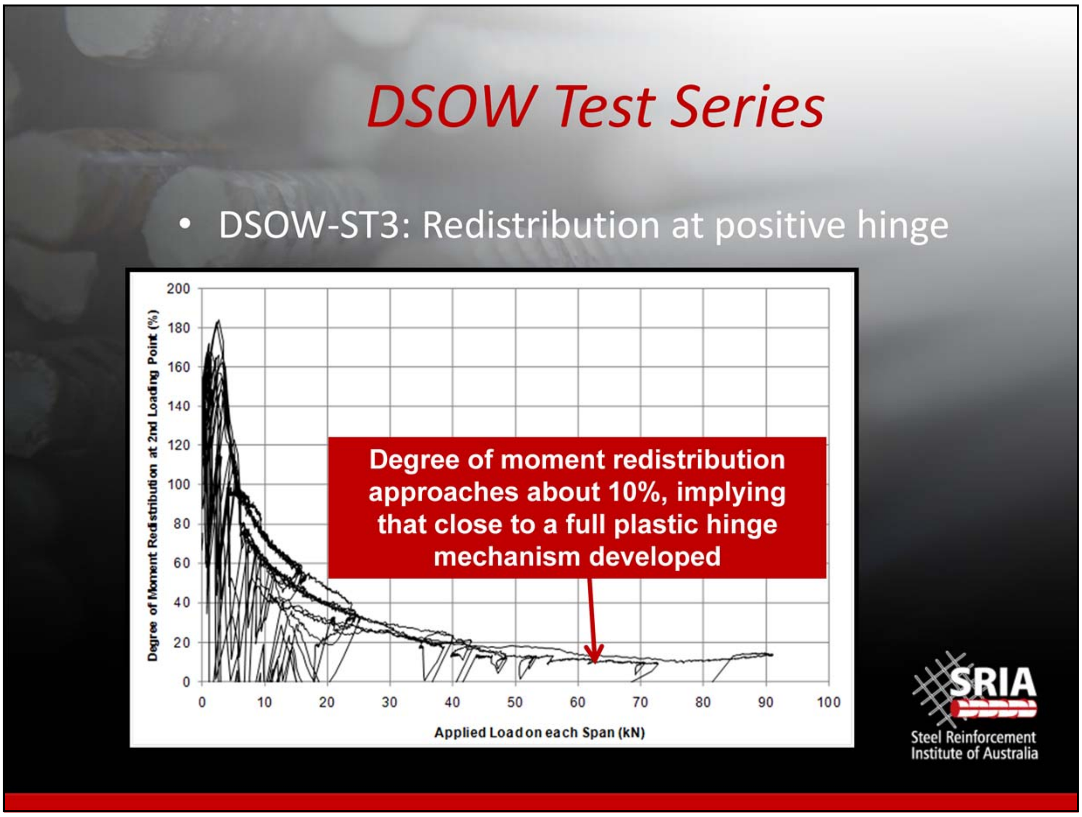


By measuring the central reaction and of course the applied loads, with the slab ends on rollers it was possible to calculate the equilibrium state of both of these slabs at all stages of loading.

These graphs are taken from Volume 3 of the Curtin Test Report, and show the development of negative bending moment at the centre support for the entire test for slabs DSOW-ST3 and ST4 with unrestrained ends.

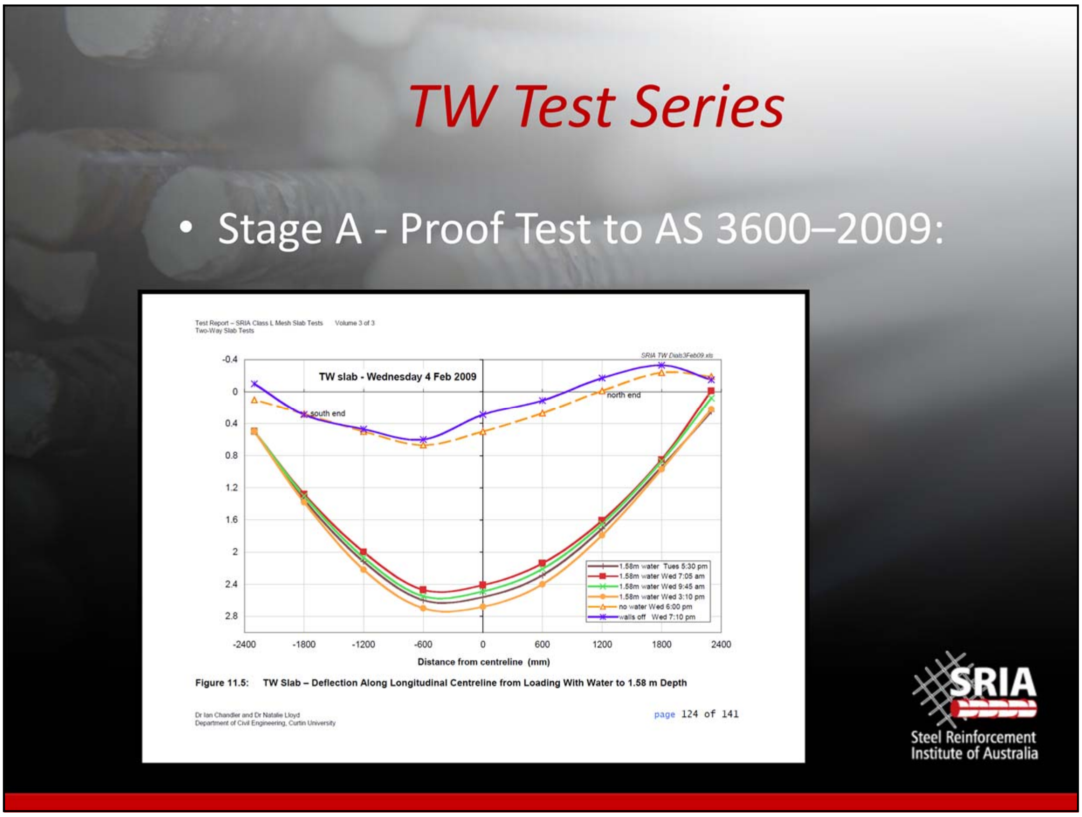


Knowing the bending moment at any cross-section at every stage of a test permits the amount of moment redistribution to be calculated using the formula shown here, which is how it is defined in AS 3600.



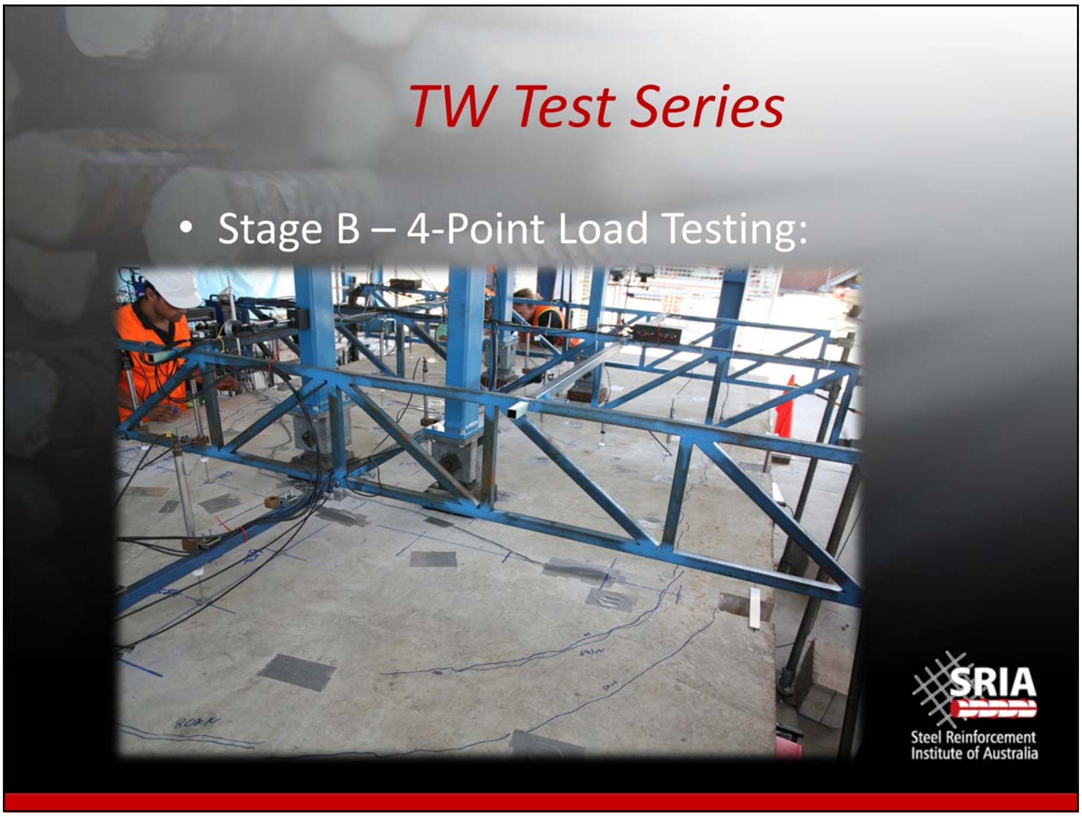
For example, this shows the the degree of moment redistribution that occurred at the positive hinge of slab DSOW-ST3, which reached a peak of 180 percent early in the test, which reduced to about 10% while approaching peak load, implying that close to a full plastic hinge mechanism must have developed, because the steel areas in the peak positive and negative moment regions were calculated based on elastic analysis. The final areas did not both agree exactly, due to steps in the mesh sizes.

This shows 1.6 metres of water applied to the two-way slab during the final stage of the strength proof test to AS 3600–2009.

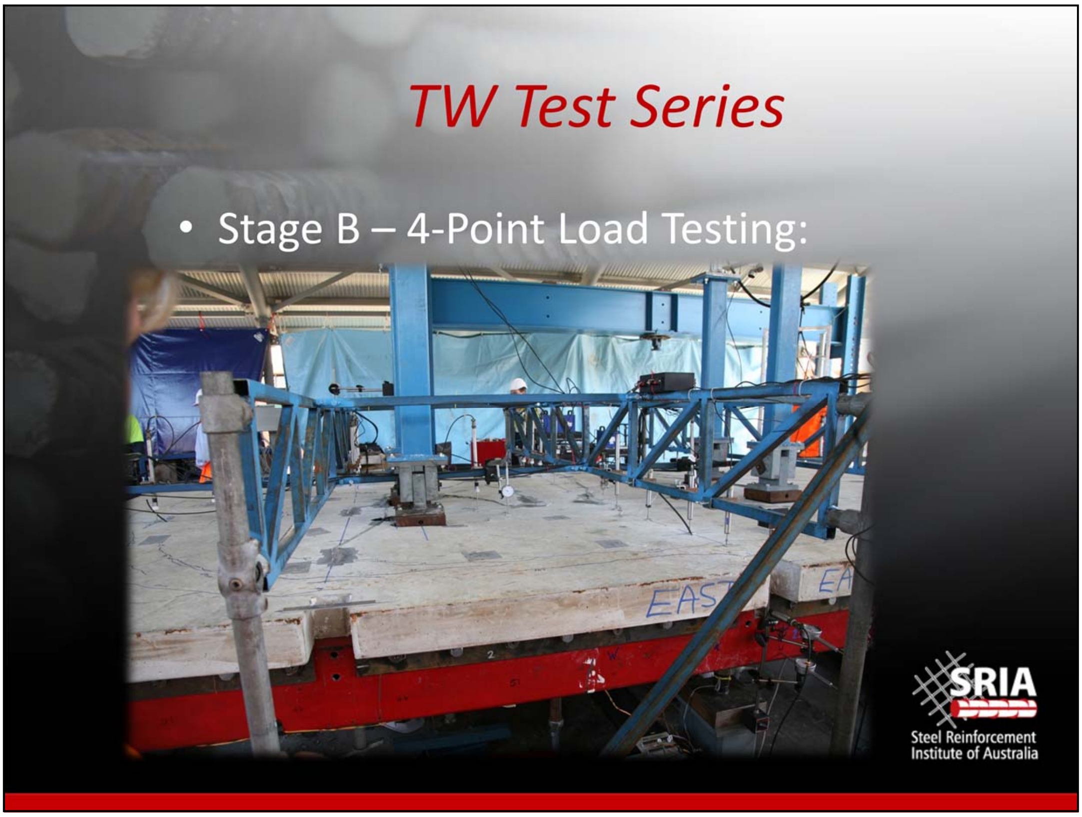


This figure from Volume 3 of the Curtin Test Report shows that the maximum vertical deflection of the slab was less than 3 mm at the end of the 24 hours.

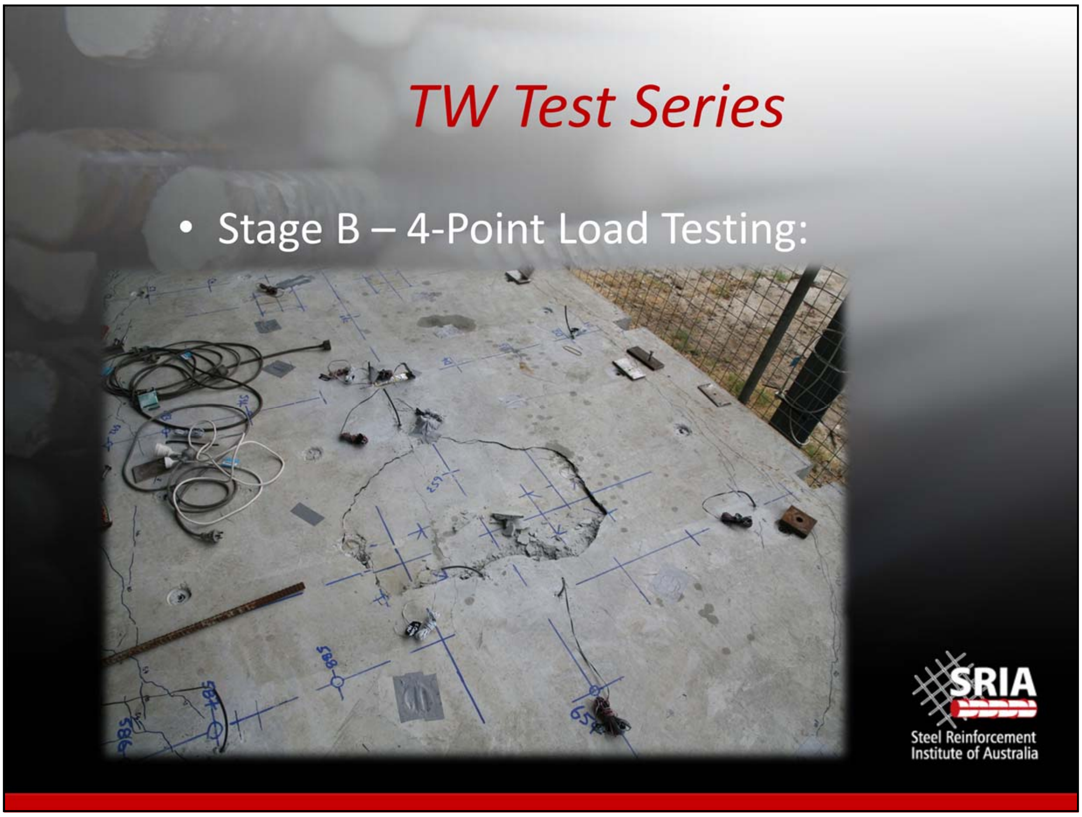
Finally the walls and tank liner were removed to expose the top surface of the slab. Careful examination did not reveal any surface cracks on the slab top face or soffit. It was concluded that the slab was uncracked, despite having supported its factored design ultimate load determined using the design bending moments from Clause 6.10 of AS 3600–2009.



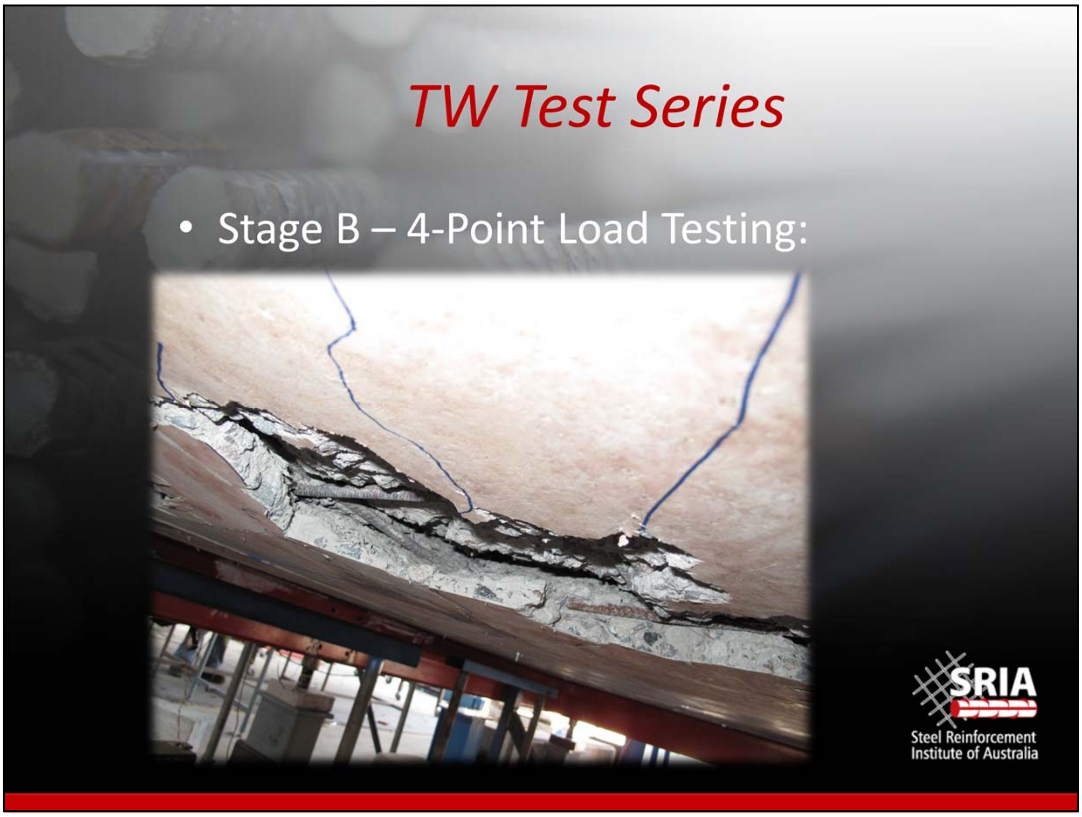
While loading the slab using the four hydraulic jacks, yield-line patterns were marked out on the top and bottom faces of the slab.



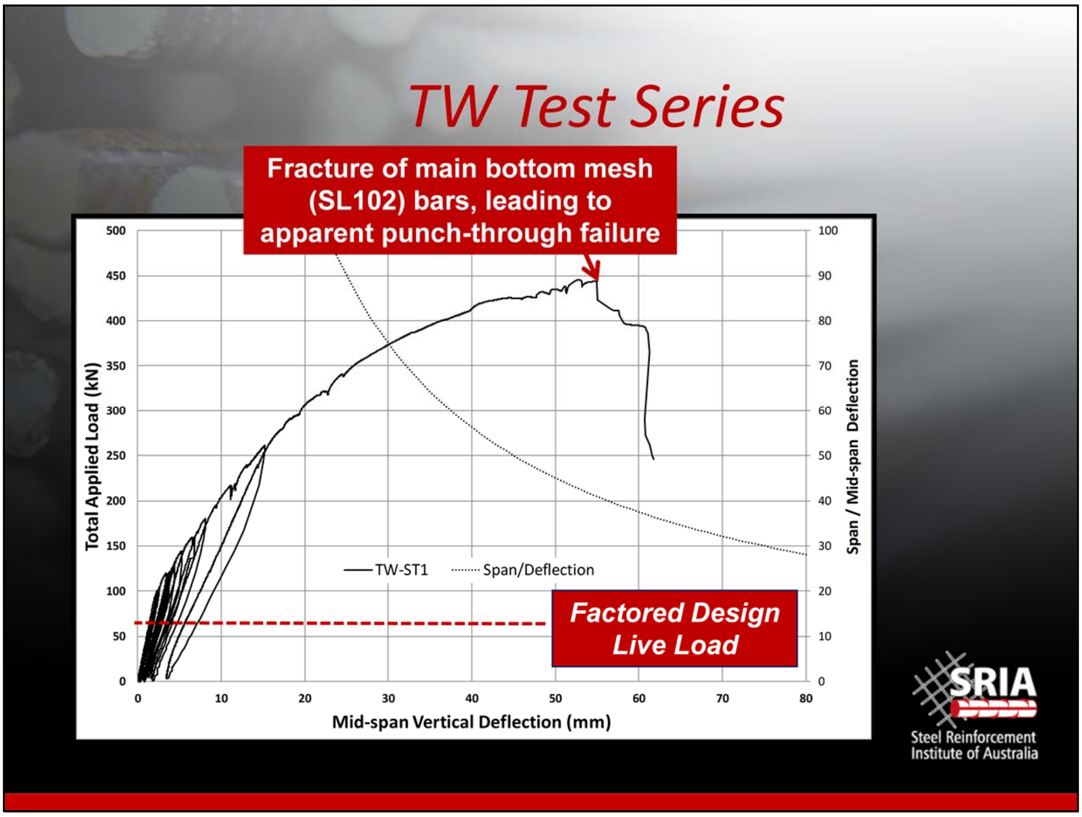
At peak load the noise from bars breaking was suddenly heard, and a shear punch-through failure appeared to have occurred under two of the loading points.



This shows the region of the punch-through, which encapsulates the peak positive moment region under two of the loading points.



Underneath the slab some of the mesh bars had broken, and it is apparent that bar fracture triggered the subsequent, secondary punch-through failure.



This shows the load-deflection curve for the whole of Stage B when the hydraulic jacks were used rather than water.

As is clearly evident, the peak load reached in the test was vastly greater than the factored design live load determined using elastic analysis in accordance with AS 3600–2009.

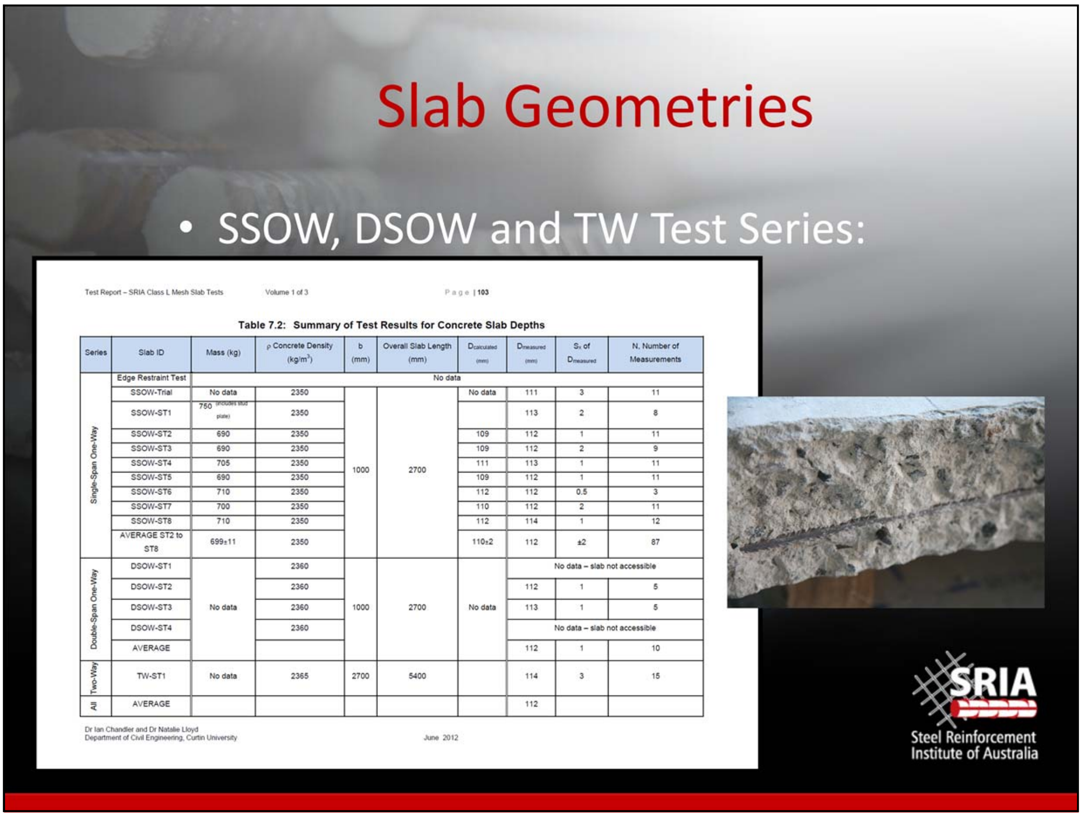


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Table 7.2: Summary of Test Results for Concrete Slab Depths

Series	Slab ID	Mass (kg)	ρ Concrete Density (kg/m³)	b (mm)	Overall Slab Length (mm)	$D_{calculated}$ (mm)	$D_{measured}$ (mm)	S_x of $D_{measured}$	N, Number of Measurements
Single-Span One-Way	Edge Restraint Test	No data							
	SSOW-Trial	No data	2350	1000	2700	No data	111	3	11
	SSOW-ST1	750 (includes stud plate)	2350				113	2	8
	SSOW-ST2	690	2350			109	112	1	11
	SSOW-ST3	690	2350			109	112	2	9
	SSOW-ST4	705	2350			111	113	1	11
	SSOW-ST5	690	2350			109	112	1	11
	SSOW-ST6	710	2350			112	112	0.5	3
	SSOW-ST7	700	2350			110	112	2	11
	SSOW-ST8	710	2350			112	114	1	12
	AVERAGE ST2 to ST8	699±11	2350			110±2	112	±2	87
Double-Span One-Way	DSOW-ST1	No data	2360	1000	2700	No data	No data – slab not accessible		
	DSOW-ST2		2360				112	1	5
	DSOW-ST3		2360				113	1	5
	DSOW-ST4		2360				No data – slab not accessible		
	AVERAGE						112	1	10
Two-Way	TW-ST1	No data	2365	2700	5400		114	3	15
All	AVERAGE						112		

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Department of Civil Engineering, Curtin University   June 2012

Detailed information about the slab geometries is contained in Volume 1 of the Curtin Test Report.

For example, actual overall slab depth measurements were recorded.

Slab Geometries

- SSOW, DSOW and TW Test Series:

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Table 7.3: Summary of Reinforcement Cover – As Cast Information and Post Mortem Information

Series	Calculated Cover, c - Bottom Reinforcement (Positive Bending) (mm) from Table 4.1	Measured Cover, c - Bottom Reinforcement (Positive Bending) (mm) Post Mortem	N, Number of Measurements	Average $d_{measured}$ from Table 4.1 (mm)	Calculated Cover, c – Top Reinforcement (Negative Bending) (mm)	Measured Post Mortem Cover, c – Top Reinforcement (Negative Bending) (mm)	N, Number of Measurements
SSOW ST1				89±0.5	21±0.5 (1)	No data	0
SSOW ST1-ST8	21±1	23±1	34				
DSOW	21±2	20±1	10	92±2	20±2 (2)	20±2	10
TW	20±1	19±2	15	88±2	26±2 (2)	25±3	6
All	21±1	21±2	59	90±2	22±2 (2)	19±2	16

Notes

(1) Calculated using the average slab depth as determined by weighing and measuring the SSOW slabs and concrete density

(2) Calculated using the average slab depth as determined from the post mortem depth measurements of the slabs

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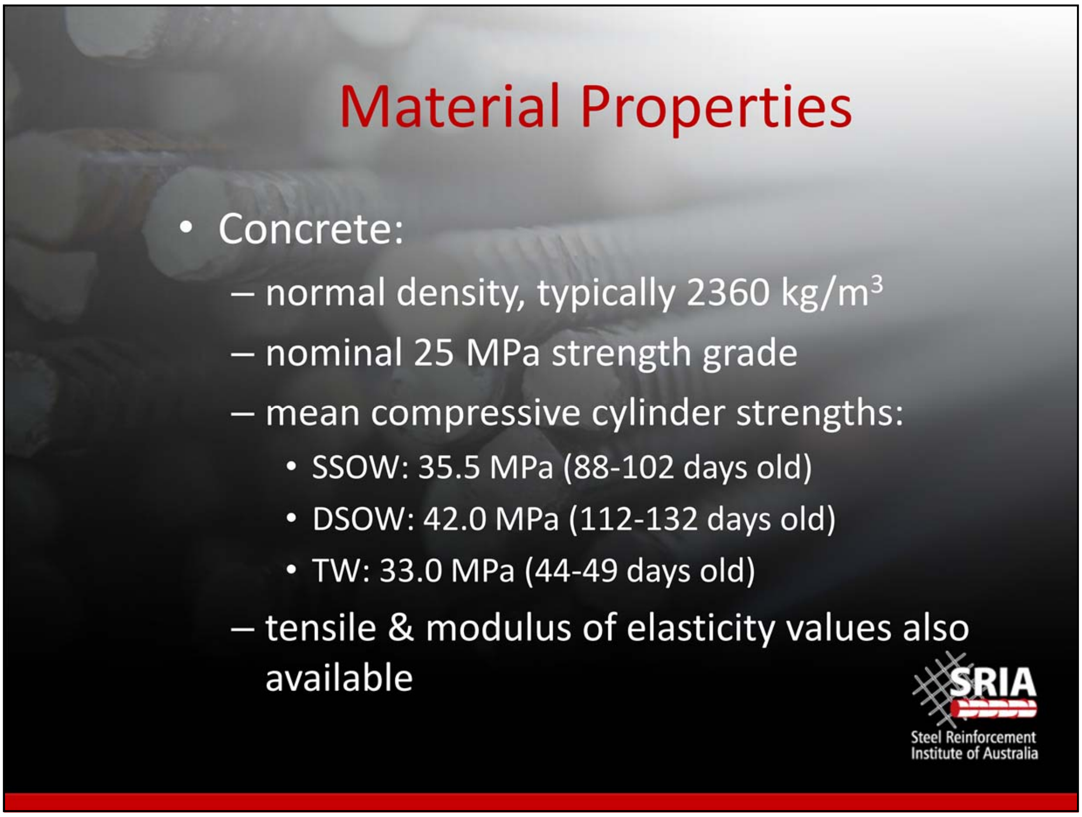
Department of Civil Engineering, Curtin University June 2012

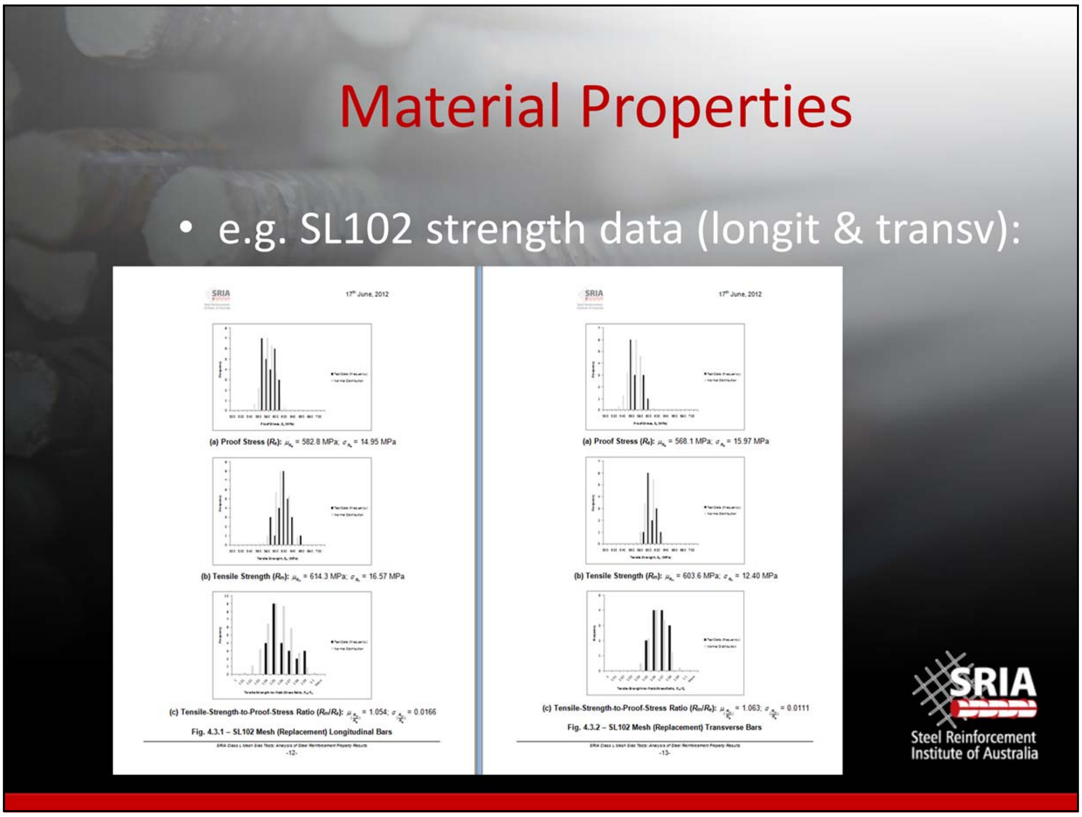
SRIA Steel Reinforcement Institute of Australia

Actual top and bottom concrete covers were also measured.

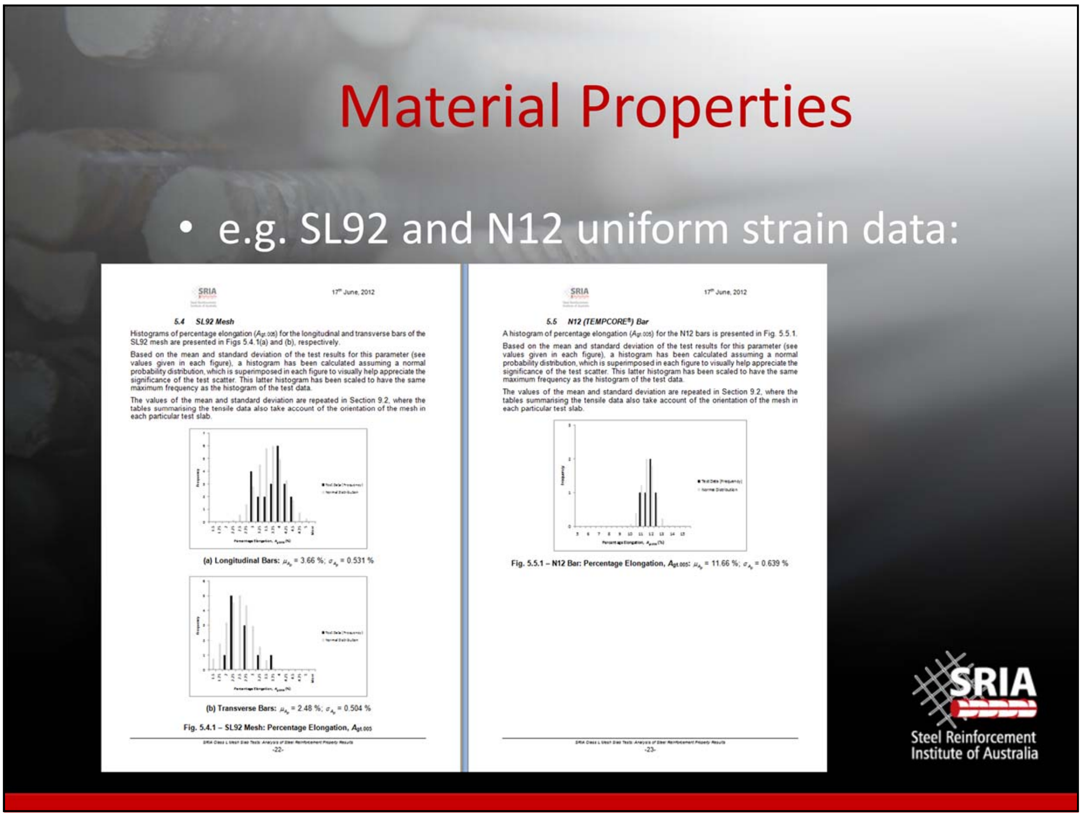


This slide summarises some of the concrete property data.

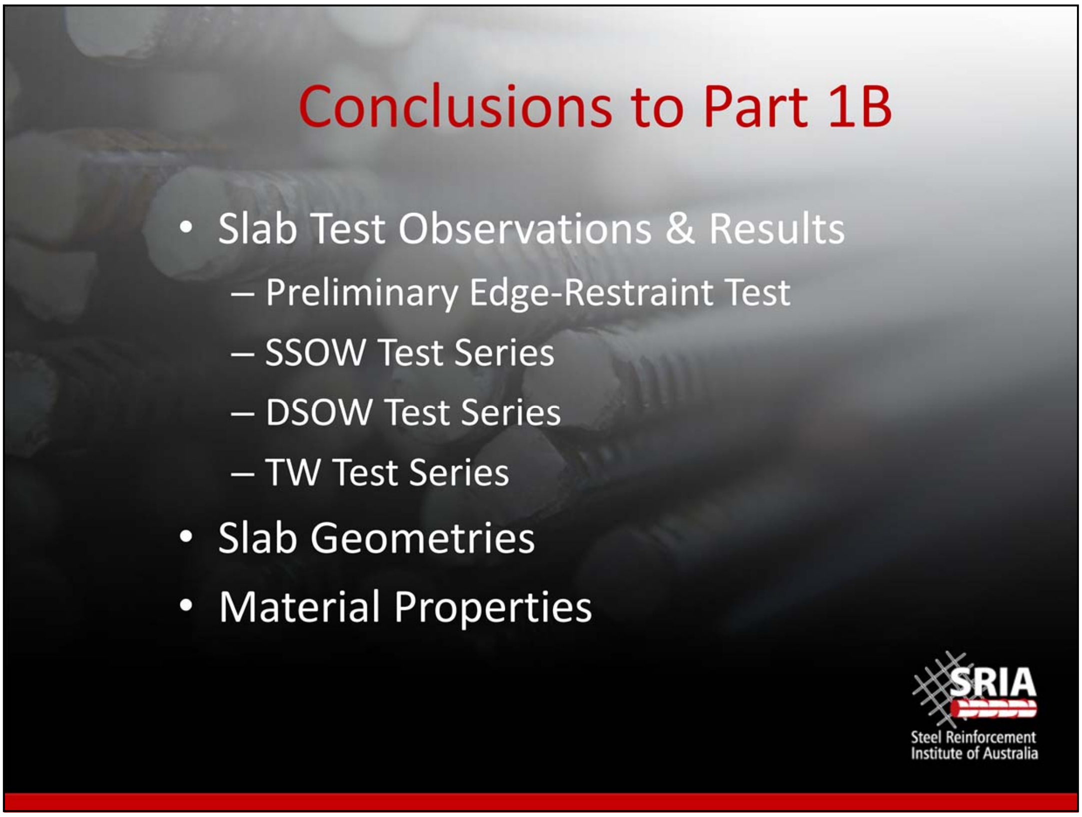
Detailed information about the reinforcing steels is available in Volume 1 of the Curtin Test Report, and also from this supplementary SRIA report.



These histograms come from the SRIA report, and show the variability of the tensile strength results for both the longitudinal and transverse bars of the SL102 mesh, and not just mean values.



Similarly, these histograms show the variability of the uniform strains for the SL92 and N12 bars.



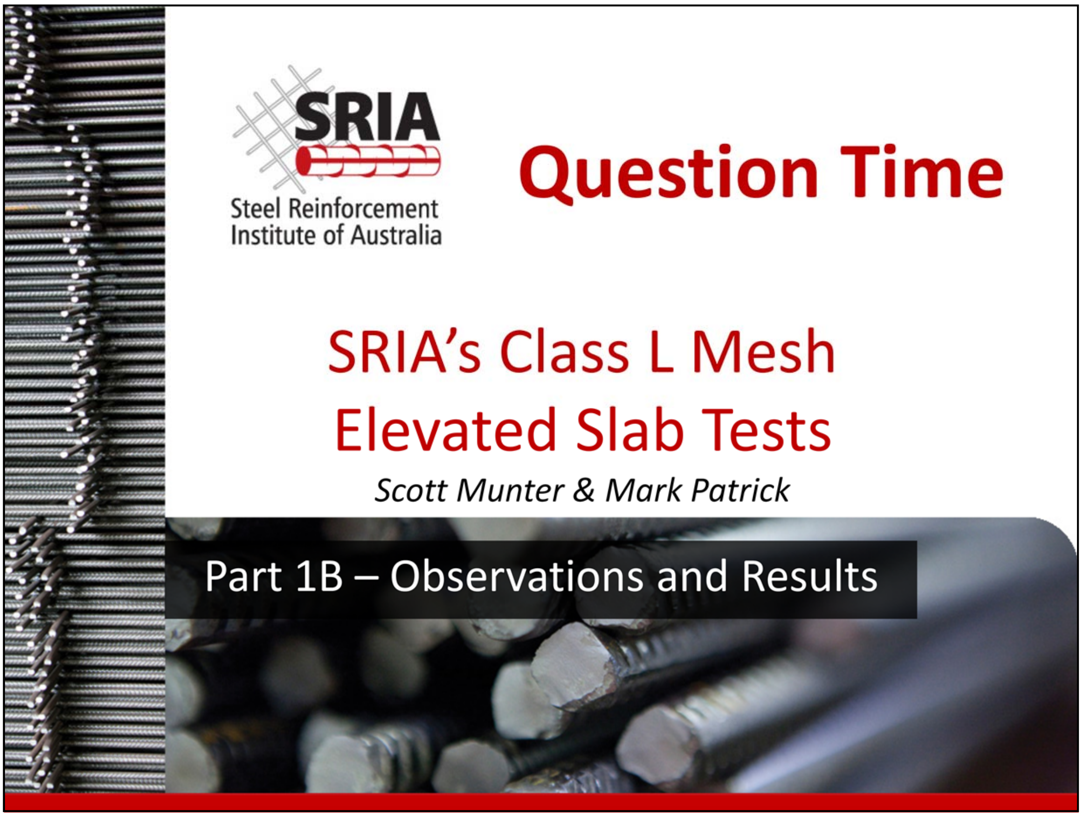
In conclusion:

The Preliminary Edge-Restraint Test confirmed that the restrained end or edge detail was satisfactory, and that compressive membrane action could develop.

Bar fracture ultimately occurred in every one of the slabs of the SSOW, DSOW and TW Test Series.

It has been shown that some of the maximum loads reached were much greater than the corresponding design ultimate load. The two-way slab proof test also showed how very conservative AS 3600–2009 can be.

Detailed information has been recorded about the slab geometries and material properties to allow in-depth analyses of the test results to be performed.


SRIA
Steel Reinforcement
Institute of Australia
Question Time
SRIA's Class L Mesh
Elevated Slab Tests
Scott Munter & Mark Patrick
Part 1B – Observations and Results