The Serviceability Testing and Analysis of Longform Steel Decking Concrete Slabs

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Abstract

This paper presents the results of testing and analysis of reinforced concrete floor slab panels using Longform steel decking. The purpose of the study is to assess the contribution of steel decking to the stiffness of the slab system and its influence on the short-term and long-term deflections. The tests were carried out under sustained loads for a period of 260 days. The study indicated that the decking steel can be included in the geometric properties of the slab section for the purpose of satisfying serviceability requirements on deflections. A set of conclusions and recommendations drawn from this investigation are presented.

Kew Words

slab systems, steel-concrete decks, composite action, deflections

Introduction

Steel decks in floor construction are widely used because of their efficiency and high strength-to weight ratio. Although all steel deck systems are primarily used as a permanent form work in composite concrete steel floor decking, many of such systems are also utilised as structural components. In these situations, special deck corrugations and/or shear studs are used to ensure full composite action under service and ultimate load limit states.

The Longform is a steel deck system manufactured by STRAMIT Industries for the purpose of providing a permanent forwork for composite steel-concrete floor slabs. The concrete slab is designed as a reinforced concrete joist system using steel bars. The steel decking is smooth and no shear studs are used as the deck is meant to act as permanent formwork only. At present, the serviceability and strength design of this floor slab system does not take into consideration the contribution of the steel decking.

The manufacturer requested the Department of Civil Engineering at Monash University to carry out experimental and theoretical research to investigate the short-term and long-term deflection response of their floor system. The purpose of the tests was to assess the contribution of the steel decking to the stiffness of the slab system and its influence on the short-term and long-term deflections. In addition to long-term testing under sustained loads, the slabs were incrementally loaded to their theoretical ultimate capacity to investigate the extent of composite action.

1- Test Set-up

1-1- General

Two simply supported concrete slabs and one two-span continuous concrete slab were cast on Longform steel decking, and loaded with a dead weight of concrete blocks for the purpose of measuring the short term and long term deflection behaviour of the slabs. The total period of loading was 260 days. Measurements of deflection, end slip, and strain in the decking were taken throughout the test period. The testing was undertaken at Monash University Civil Engineering Laboratories between May 19 1997 and February 5 1998.

1-2- Slab details

The slab details are given in Table 1. Reinforcing details for the slabs are given in Figure 1.The north-simply supported slab (north-ss) had a coating of form release oil applied before the concrete was cast in order to eliminate chemical bond between the concrete and the decking.

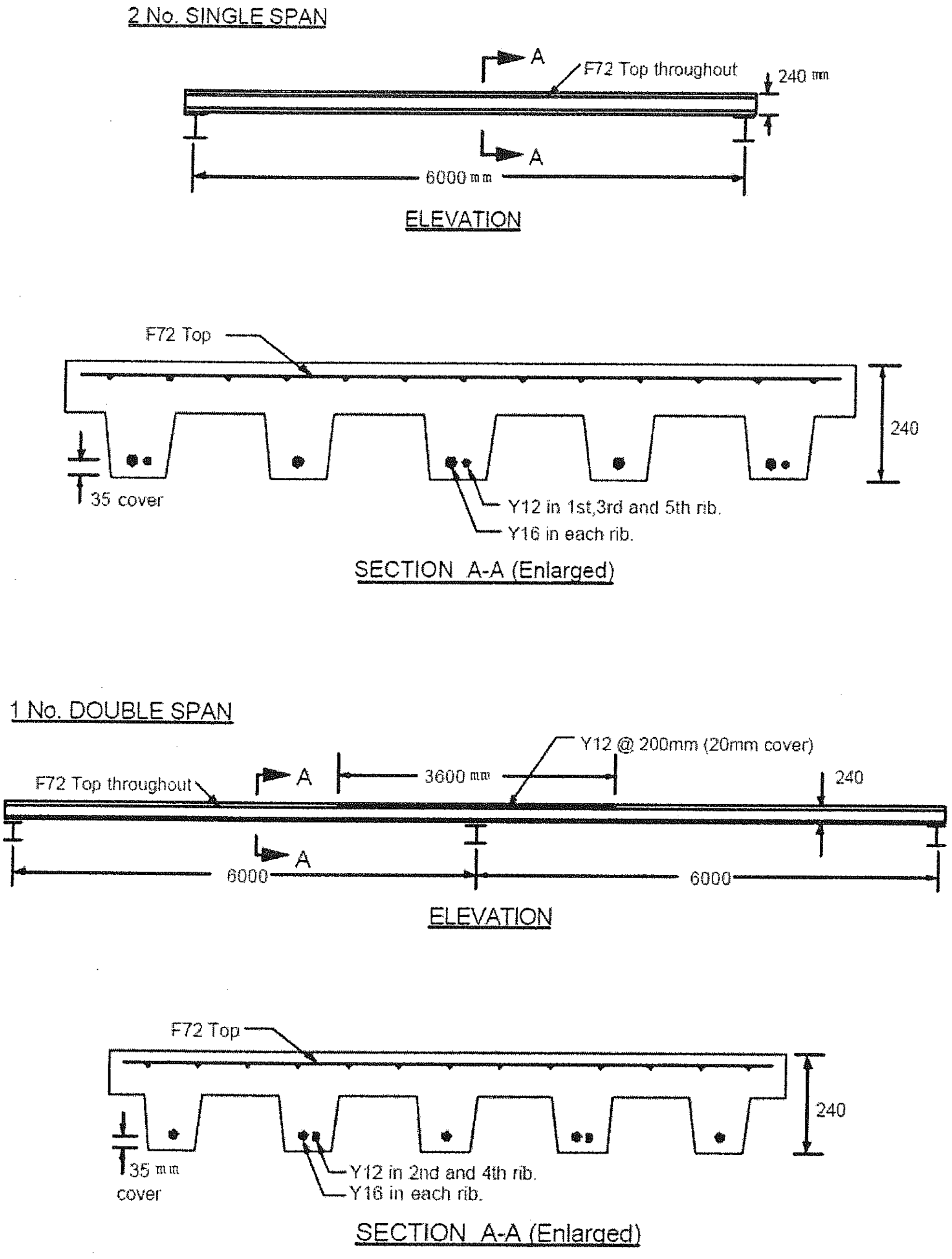

Figure (1) Slab reinforcing details.

Table (1) Details of slabs.

Name	number of spans	span length	slab width	overall depth	decking debonded
		M	mm	mm	
North-ss	1	6	1665	240	yes
South-ss	1	6	1665	240	no
Notrh-cont. & South-cont.	2	6	1665	240	no

1-3 Concrete Strength

Concrete cylinders were tested during the period of slab testing. Based upon a method presented in Gilbert (1988) these values can be used to define a curve relating concrete strength to time (Figure 2). Based upon the usual relationship between strength and elastic modulus as presented in Australian Standard AS 3600 Concrete Structures (1994);

$$E = \rho^{1.5} 0.043\sqrt{f_{cm}}$$

and assuming a concrete density of $2400 kg/m^3$, elastic modulus has been plotted against age of the concrete in Figure 3.

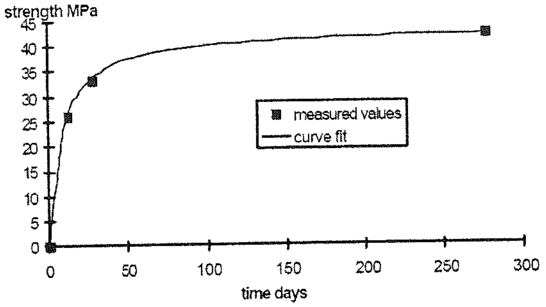

Figure (2) Concrete strength versus time.

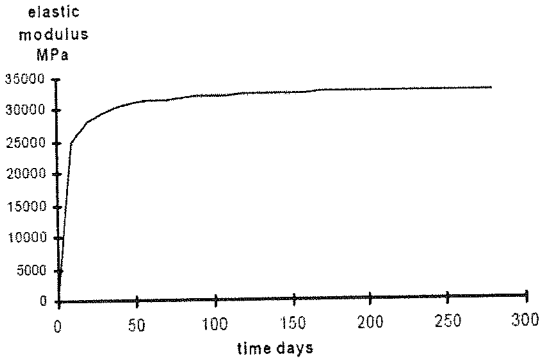

Figure (3) Concrete elastic modulus versus time.

1-4 Loading

The self weight of the slab was calculated as 3.9 kPa. Live load was applied using concrete blocks, evenly spaced over the slab surface to achieve the desired loading. The long term applied load was 2.2 kPa, determined as follows:

superimposed dead load = 1.0 kPa
long term live load = 0.4 x 3 kPa = 1.2 kPa
total = 2.2 kPa

The short term applied load was 3.0 kPa, determined as follows:
superimposed dead load = 1.0 kPa
long term live load = 0.7 x 3 kPa = 2.1 kPa
total = 3.1 kPa,

but rounded to 3.0 kPa. The loading history is summarized in Table 2.

Table (2) Loading summary.

Day	Data	loading event
(-17)	May 1 1997	slabs cast
1	May 19 1997	self weigth(slab falsework stripped out)
15	June 2 1997	1.0 kPa applied
15	June 2 1997	2.0 kPa applied
15	June 2 1997	3.0 kPa applied
15	June 2 1997	1.2 kPa applied
16	June 3 1997	2.2 kPa applied
106	September 1 1997	3.0 kPa applied
106	September 1 1997	2.2 kPa applied
260	February 2 1998	3.0 kPa applied

2- Test Results

2-1- Short Term Deflection

The short term stiffness of the slab can be calculated from the loading events that occurred on May 19, June 2, September 1, and February 2 (Figures 4 & 5).

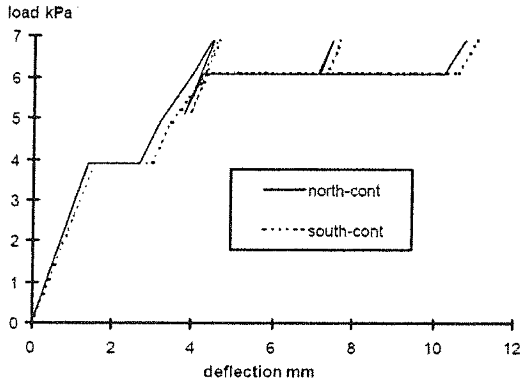

Figure (4) Load versus deflection - continuous slab.

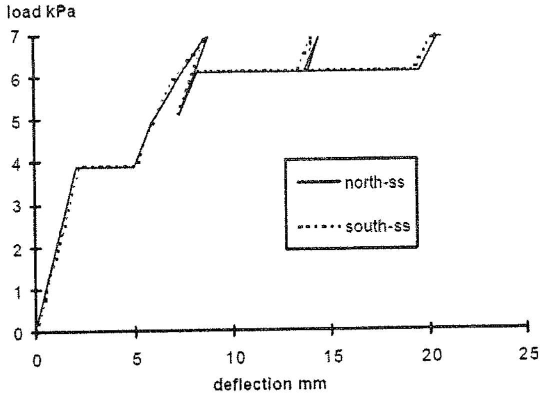

Figure (5) Load versus deflection - simply supported.

Table (3) Short - term stiffness values.

Data	**day**	**Event**	**concrete age Days**	**Average stiffness (kPa/mm)**	
				continuous	**simply supported**
195/97	1	Self weitgth (flasework stripped out)	18	2.63	1.80
2/6/97	15	3.0 kPa applied	32	2.44	1.23
1/9/97	106	0.8 kPa applied	123	2.33	1.11
2/2/98	260	0.8 kPa applied	277	1.66	0.81

A reduction in stiffness is evident with increasing age. This is attributable to increased cracking as the concrete creeps, as discussed in Section 4.1.

2-2- End Slip

Slip between the concrete and the Longform was measured at each end of each slab. End slip occurs when full composite action between the concrete and the Longform is lost. At the end of the serviceability testing period (260 days), the applied load was increased gradually to nearly the theoretical ultimate strength load. This was done to investigate the extent of composite action.

The results indicate that slip between the Longform and the concrete did not occur until a load of 10 kPa was reached on the north-ss slab. This slab had a coating of form release oil applied before the concrete was cast in order to eliminate chemical bond between the concrete and the decking. Slip did not occur in the south-ss slab, or the continuous slab.

2-3- Long Term Deflections

The long term applied load on the slabs was 2.2 kPa. The additional long-term deflection due to this load over time is plotted in Figure 6 as the long-term deflection coefficient:

Coef. = (total deflection at time t - short term deflection) / (short term deflection)

All spans displayed very similar long-term deflection coefficients.

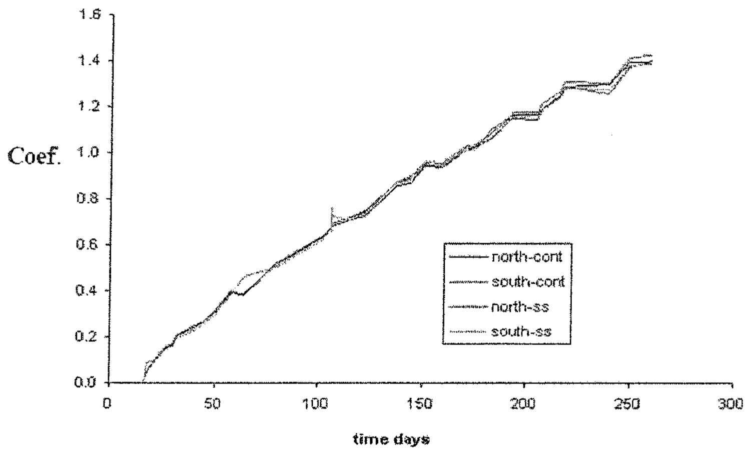

Figure (6) Creep and shrinkage coefficient versus time.

3- Theoretical Analysis

3-1- Short Term Deflection

The short term elastic stiffness of a concrete slab depends upon the elastic modulus of the concrete and the effective second moment of area of the slab cross section. The elastic modulus values are presented in Section 2.3, and these increase with age. The second moment of area of the slab cross section depends upon the extent of cracking. Various values can be calculated as follows (in decreasing order of magnitude):

$I_{uncracked}$ is the second moment of area of the combined concrete and steel cross section (cracking ignored)

I_{gross} is the second moment of area of the concrete cross section (steel and cracking ignored)

$I_{cracked}$ is the second moment of area o f the cracked concrete and steel cross section

When cross sections are not fully cracked, the second moment of area will lie between Iuncracked and Icracked, and Branson's equation is usually used to calculate an effective second moment of area, Ieff (Australian Standard AS3600 - Concrete Structures),

$$I_{eff} = I_{cracked} + \left(I_{gross} - I_{cracked}\right)\left(\frac{M_{cr}}{M_s}\right)^3 \leq I_{gross}$$

where Mcr is the cracking moment for the gross cross section, and Ms is the short term moment. To further allow for the fact that the extent of cracking varies at different cross sections along the length of a beam, an effective second moment of area, Ieff, *of the member* is calculated as follows (Australian Standard AS3600 - Concrete Structures):

for a simply supported span: I_{eff} of the member = I_{eff} of the midspan cross section

for the end span of a continuous beam: I_{eff} of the member = (0.5 x I_{eff} at midspan) + (0.5 x I_{eff} at support)

This calculation of I_{eff} assumes that cracking is only attributable to the short term loading, whereas cracking alsodevelops with age due to the combined effects of shrinkage and creep under the long term loading. In these tests the beam moments under the short term loading were below, or only just above the cracking moments. Therefore the effective moment of area of the continuous slab calculated using this method was very close to the uncracked value. If, however, the section was already cracked (due to the combined effects of shrinkage and creep under the long term loading) when the short term loading was applied, the calculated stiffness will overestimate the real stiffness. This behaviour is discussed in the Commentary to Australian Standard AS3600-Concrete Structures, which recommends an upper limit on I_{eff} of 0.6 x I_{gross}. This recommendation has been adopted in the calculated values of Ieff presented in this paper.

The theoretical stiffness of the simply supported and continuous slabs was calculated using the methods described above, and is plotted in Figures 7 and 8.

For the simply supported slab, the measured stiffness decreased with time, and moved from the uncracked to the cracked or effective value. The cracked and effective second moments of area are similar, because under the applied short term load (3.9 kPa DL + 3.0 kPa LL) the midspan moment was approximately double the cracking moment.

For the continuous slab, the measured stiffness again decreased with time, and moved from the uncracked to the cracked value. Provided that an upper limit on I_{eff} of 0.6 x I_{gross} is used, I_{eff} is a good predictor of the stiffness under short term loading.

It is therefore recommended that the value of I_{eff} calculated in accordance with Australian Standard AS3600-Concrete Structures (including an upper limit on I_{eff} of 0.6 x I_{gross}) be used for the determination of short term deflections.

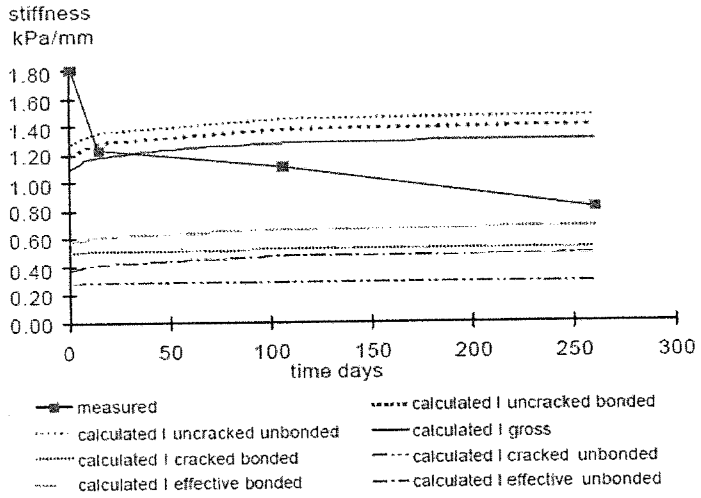

Figure (7) stiffness versus time – simply supported slabs.

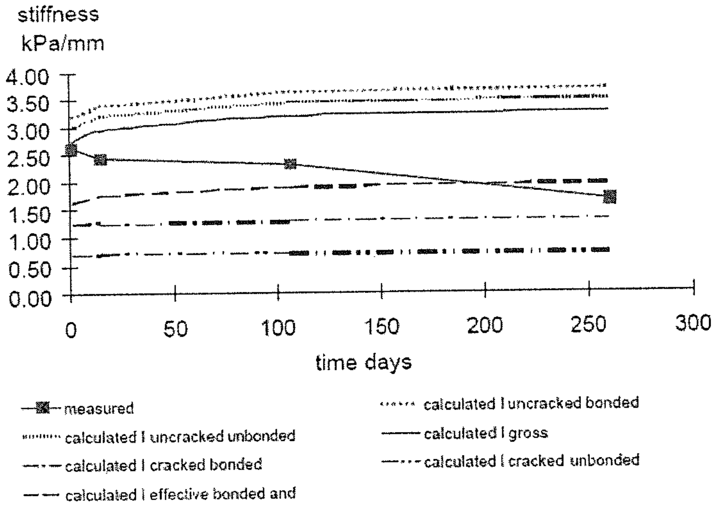

Figure (8)Stiffness versus time - continuous slab.

The variation in the calculated cracked second moment of area between the bonded and unbonded slabs is clearly evident in the Figures. The bonded slab is significantly stiffer. It is therefore further recommended, based upon these results, that the cracked second moment of area of the slab be calculated taking account of the presence of the Longform steel decking.

3-2- Long Term Deflection Factor

Figure 9 shows the long-term deflection coefficient obtained from the measured deflections and those calculated on the basis of AS3600 (1994) and ACI-318 (1995). This coefficient is defined as the multiplier to be applied to the short-term deflection under the sustained load to account for the *additional* deflections due to the combined effects of shrinkage and creep.

$$k_{cs} = 2a, a = (10.6A_{sc} / A_{st}) \geq 0.4 \qquad \text{AS3600(1994)}$$

$$k_{cs} = \xi a, a = 1/(1 + 50\rho') \qquad \text{ACI-318(1995)}$$

where k_{cs} is the long-term deflection factor, a is a parameter which takes into consideration the beneficial effect of compression steel Asc in the section and ρ' = Asc/(b d). The time-dependent parameter ξ can be taken as (ACI-318):

5 years or more	2.0
12 months	1.4
6 months	1.2
3 months	1.0

For the present slabs, Asc = 64 mm2 per rib, Ast = 383 mm2 (incl. a portion of the decking), ρ' = 64/(333 * 200) = 0.001, a= 0.95 (ACI) and a= 0.9 (AS3600).

There are a number of mathematical expressions in literature devised to represent the effects of creep and shrinkage. One of these that account for the combined effect of creep and shrinkage in concrete members is presented here. It is an exponential equation proposed by Ulitskii (A method of computing creep and shrinkage deformation of concrete for practical purposes) cited in Branson (1977):

$$C_t = (1 - e^{-Bt})C_u$$

If we introduce the effect of the compression steel to this equation:

$$k_{cs} = aC_t = a(1 - e^{-Bt})C_u$$

where C_t is the long-term coefficient at any time t, C_u is the ultimate coefficient and B is a constant. A value of B= 0.006 and C_u = 2 seem to give close results to the measured ones. A C_u value of 2 is used in line with the ultimate coefficient as per ACI-318-95 and AS3600.

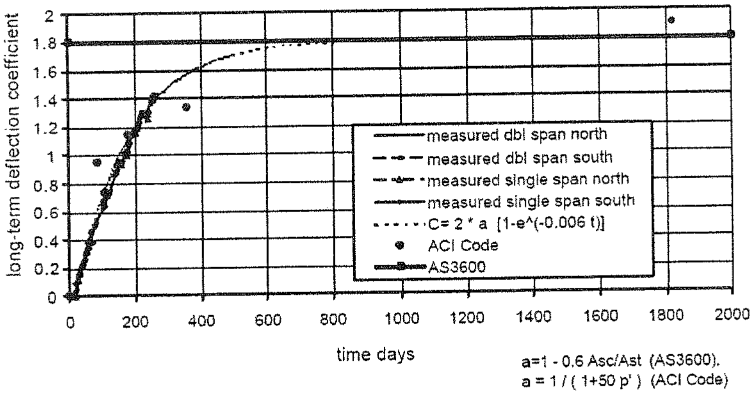

Figure (9) Comparison of long-term deflection factors.

4- Design Ramifications

The effect of including the Longform decking in the calculation of deflection of the ribbed slab is shown in Figure 10. The curves have been plotted for a 240mm thick end span of a continuous slab and show the live load carrying capacity versus span based on long term deflection only. The concrete compressive strength was assumed to be 32MPa and the total deflection of the slab limited to Span/250. Curves for other slab thicknesses, concrete strengths, deflection criteria and span configuration show a similar trend to those given here.

Three methods have been used to determine the live load carrying capacity based on serviceability considerations and these are briefly described below.

4-1- Method I

The simple span-to-depth ratio method is the criterion used for the first curve. The effect of the ribs has been considered by assuming an Ief value similar to that of a T-section as described in Clause 8.5.4 of AS3600 - 1994. The presence of the Longform decking has been ignored. As can be seen in Figure 10, this method gives the most conservative results.

4-2- Method II

A more detailed calculation has been performed by determining a value for Ief as given in Clause 8.5.3 of AS3600 - 1994. Once again the decking was ignored and only the positive reinforcement was taken into account in the computations. This method gives a higher live load carrying capacity than the span-to-depth ratio method.

4-2- Method III

The recommendations based on the present investigation have been used as the basis for the third curve. The effect of the decking is taken into account by including any portion in tension as part of the tensile reinforcement in positive bending. The bottom flange of Longform is taken as contributing to the value of the multiplier kcs to determine the long term deflection. This method gives the highest live load carrying capacity.

The use of Method III allows Longform slabs to span further for a specific live load. The additional span varies from approximately 300mm to 600mm above that determined using Method II and as much as 800mm to 1200mm above that using Method I.

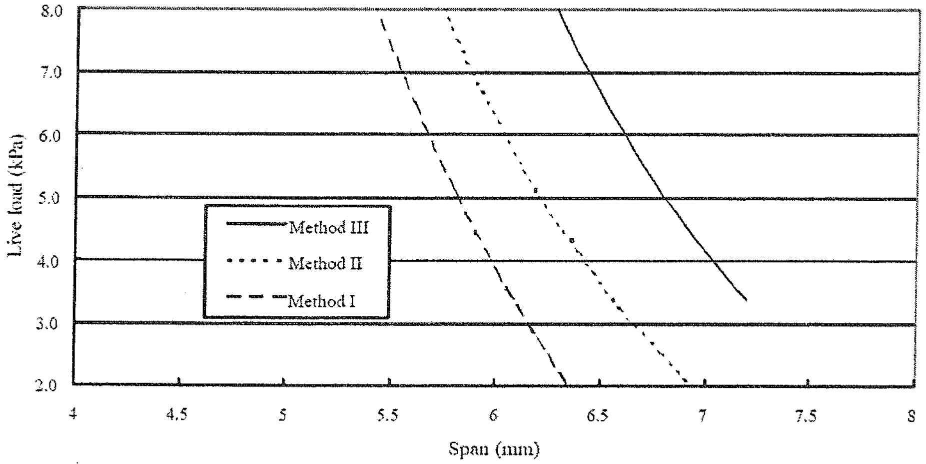

Figure (10) Span vs live load-comparison of three methods.

5-Conclusions

Based on the test results and the theoretical analysis presented in this paper, the following set of conclusions and recommendations are drawn:

- It is recommended that the value of I_{eff} calculated in accordance with Australian Standard AS3600-Concrete Structures, be used for the determination of short-term deflections (including an upper limit on I_{eff} of 0.6 I_{gross})
- It is recommended that the cracked second moment of area of the slab be calculated taking account of the presence of the Longform steel decking , for determination of I_{eff} .
- A time-dependent long-term deflection factor may be estimated on the basis of an exponential equation:

$$k_{cs} = aC_t = a(1 - e^{-0.006t})C_u$$

where C_t is the long-term coefficient at any time t in days, C_u is the ultimate coefficient with a value of 2 as per AS3600 Code, and a is a reduction factor to account for the beneficial effect of compression steel in the section as per AS3600: $a = 1 - 0.6A_{sc} / A_{st} \geq 0.4$.

- Inclusion of the Longform steel decking in the calculation of stiffness and long-term deflection factor has resulted ina more economical use of the Longform slab system. Higher spans can be achieved for a given live load and crosssectionaldetails.

6- Acknowledgments

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