UNDERSTANDING THE COMPOSITE CHARACTERISTICS OF STRESSED-SKIN PANELS – TRIBUTARY WIDTH*

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ABSTRACT

The composite properties of stressed-skin panel (SSP) systems are characterised by the interaction of the joist with the sheathing – composite action – and the portion of the sheathing acting with the joists – the tributary width. A discussion on the tributary width forms the focus of this paper. An analysis, which has been conducted considering the pattern of the strain distribution in the sheathing, is presented. It uses laboratory data of a major research project conducted at the University of Technology, Sydney, between 2002 and 2007 [1]. This analysis indicates that under strict conditions, in particular structurally glued interlayers, a large portion of the sheathing contributes to the structural behaviour of SSP structures. A better use of the mechanical properties of the panels is achieved as a consequence. The effects of discontinuities in the sheathing have also been identified, that is, such event causes a significant reduction of the sheathing contribution and a considerable loss of stiffness.

1. INTRODUCTION

In stressed-skin panel (SSP) structures, the sheathing is attached to the joists with the help of a structural adhesive. Thus, it is anticipated that portions of the sheathing act compositely with the joists. As a result, the sheathing takes higher intensity of stress, maximising the use its material properties. Further benefits also include the ability to bridge, longer span and/or shallower floor structures [2], thus providing economic and architecturally favourable floor constructions.

The contribution of the sheathing to the structural performance of the floor is characterised by the composite action (interaction between the members) and the level of the sheathing contribution (tributary width, also called shear lag). They are respectively assessed with the strain distribution through the depth of the SSP section – vertical axis – and with the strain distribution in the sheathing – orthogonal direction to the span of the deck (Figure 1). Figure 1 also shows that these strain distributions should concord. Thus, the contribution of the sheathing is maximised by a high/full degree of composite action.

This paper focuses on the magnitude of the sheathing contribution and presents an empirical investigation of this aspect. Whilst, the analysis of composite action in SSP can be found elsewhere [3].

Vertical and orthogonal strain distributions

(200-mm I-joist box cross-section)

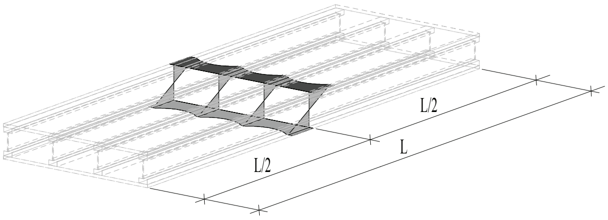

Figure 1. Stress distribution in an SSP structure.

2. LITERATURE REVIEW AND BACKGROUND

Estimating the tributary width accurately is a fundamental aspect of a safe design of SSP structures. But it can be difficult to assess, that is, the tributary width is not uniform along [4, 5] and across [6] the span because of stress transfer and shear deformation respectively. It is anticipated that peaks of stress occur where the panel is attached to the joists and troughs of stress are located in the portion of panel between the joists. Quantifying the tributary width also depends on the material properties of and the stress distribution in the panels.

Approximating the tributary width may thus prove complex [4]. As mentioned above, it is not uniform or constant. In addition, it relies on material data, which are not always available, even in specialised literature.

In the 1960s, Möhler, Abdel-Sayed and Ehlbeck [7] carried out works on the tributary width of plywood sheathings and derived a geometric function (1), which accounts for the elastic orthotropic properties of the sheathing and the geometric dimensions of the floor. The buckling propensity of the compression flange is also considered together with the shear deformation in the panel.

$$b_{ef} = 2L\frac{\left(\lambda_1 \tanh\alpha_1 - \lambda_2 \tanh\alpha_2\right)}{\pi\left(\lambda_1^2 - \lambda_2^2\right)} \quad (1)$$

For design convenience, however, an “idealised” tributary width is produced by equating the stress under the geometric curve of the non-linear distribution and a fictive uniform rectangular distribution (Figure 2). Therefore, the panels take equal amounts of stress and the real and idealised T- or I-beams have similar ultimate and service performances [4].

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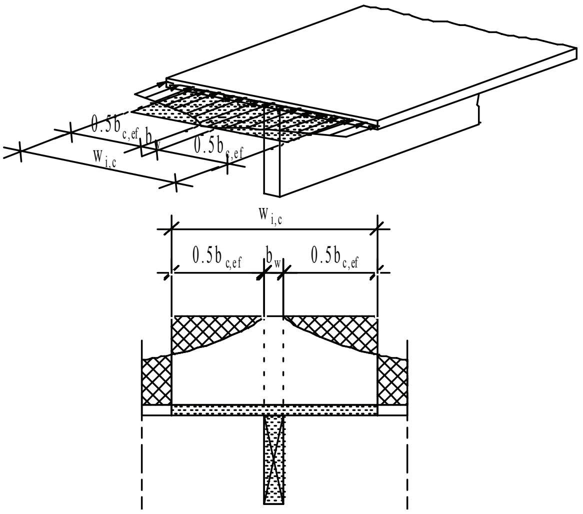

Figure 2. Tributary width of the sheathing.

Different codes around the world have adopted an idealisation approach and provide accessible directives for approximating the tributary width. For example, (2) can be found in Eurocode 5 (EC5) [8].

$$b_{ef} = \min \left| \begin{array}{l} b_f \\ c_{SL} L \\ {}^{*}c_{PB} h_f \end{array} \right| \tag{2}$$

*sheathing in compression only.

A comprehensive analysis of the guidelines available in the codes and other handbooks is presented elsewhere [1].

3. APPROACH FOR THE EMPIRICAL ASSESSMENT OF THE TRIBUTARY WIDTH

The empirical assessment aims to identify the contribution of the sheathing using an empirical approach – measurements of a series of strain gauges (Figure 3) – and to understand the effects of discontinuities1) or gaps in the sheathing – "damaged" state – complete the scope of this discussion.

The qualitative analysis corresponds to an assessment of the pattern of the orthogonal strain profile/ distribution in the sheathing. Conformingly to the assumption that flexural action – four-point bending (Figure 4) – generates normal stresses in the sheathing [9], the full contribution of the sheathing is characterised by a uniformed distribution of the strain. Very small deviations from such distribution may, however, be caused by the occurrence of shear deformations [6]. Strain intensity with some minimal variations can therefore be accepted as uniform, in other words complying with the assumption of idealisation put forward by Amana and Booth [4] and implemented in EC5 [8]. This distribution is hereafter qualified as "distinct" pattern.

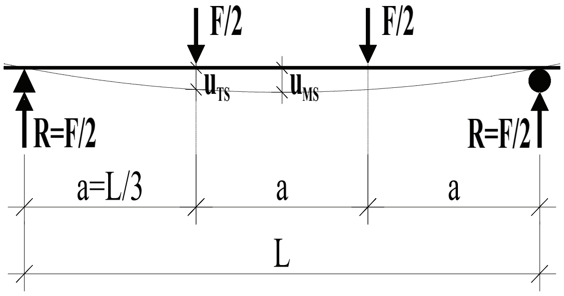

Figure 4. Four-point bending test principle.

In the sheathing areas about the supports and discontinuities, the pattern of the strain profiles is anticipated to be "disturbed", indicating some decrease of the structural contribution of the sheathing. Foschi [10] and Ozelton and Baird [9] suggest that at these locations the sheathing contribution is characterised by the occurrence of normal stress peaks and troughs in the sheathing located in the portions of the panel directly superimposed to the joists and in the unsupported portions between the joists, respectively. The magnitude of the variations between the peaks and troughs can be viewed as indicators of the alteration level of the sheathing contribution. This section of the analysis thus focuses on identifying this pattern – hereafter described as the "contra-distinct" pattern – in the specimens' sheathing.

Furthermore, discontinuing the sheathing is anticipated to modify the strain distribution over the depth of the

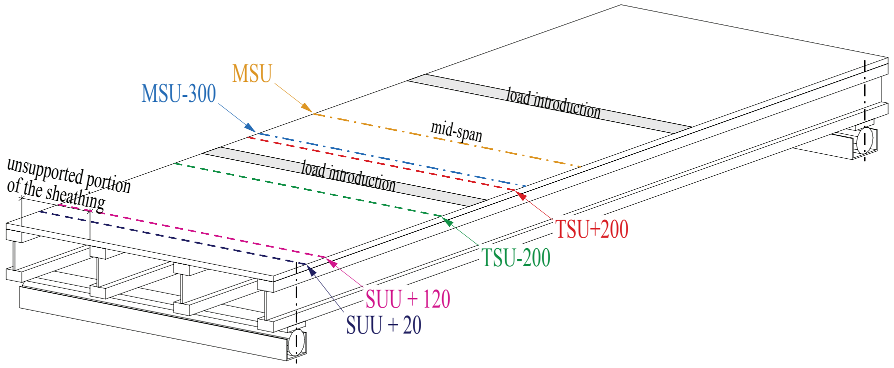

Figure 3. Arrangement of the strain gauges series on the specimen's sheathing.

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1) The sheathing is discontinued by inflicting a cut in the maximum bending moment zone – 150mm from the mid-span

specimen cross-section, thus indicating that the composite action deteriorates [1]. Such phenomenon has also been reported by other researchers [11, 12, 13].

4. ASSESSMENT OF THE TRIBUTARY WIDTH

The analysis starts with a discussion of the test data of the specimens in healthy state (continuous sheathing) and corresponds to a qualitative comparison of the measured strain profiles and the distinct distribution pattern (refer to Section 3). It continues with an examination of the effects of sheathing discontinuities, that is, qualitative assessments of the experimental data versus the contra-distinct pattern (refer to Section 3).

4.1 ANALYSIS OF THE TRIBUTARY WIDTH – HEALTHY-STATE SPECIMEN

In the healthy state (continuous sheathing), it is anticipated that the measurements of the strain gauges installed on the sheathing tally with the distinct pattern. Hereafter, this analysis is conducted considering the test data of two representative specimens C08-01 and C08-03 (Figure 5). Furthermore, C08-01 and C08-03 data are complementary.

Starting with the upper sheathing of both specimens, the strain measurements (TSU and MSU readings) arguably fail to agree with the distinct pattern. The main divergence relates to the locations of the peaks, which do not occur on the joists. However, it can be observed that high strains were measured across the sheathing, suggesting an effective structural contribution from the sheathing.

In the lower sheathing (TSL and MSL readings), the measured strain profiles of both specimens agree well with the distinct pattern. The variation is moderate (less than 10%) and the peaks of strain coincide with the joist locations whilst the troughs of strain are located in the portions between the joists – cantilevered portions of the sheathing.

The control gauges, CK (TSU–200) and CK (TSL–200), exhibit equivalent strain readings/ magnitudes to that of their corresponding gauge series. This verifies that the deck behaves symmetrically and confirms that the whole sheathing takes a large intensity of axial stress.

The strain distribution in both the upper and lower sheathings, in which large intensity of strain occurs in the cantilevered portions of the sheathing and at the joists, seems to indicate that the portion of the sheathing contributing to the structural responses of the deck is significant. It is therefore legitimate to assume that both sheathings act (fully) compositely with the joists. Thus, they experience intense axial stresses, which results in the maximisation of the use of their mechanical properties.

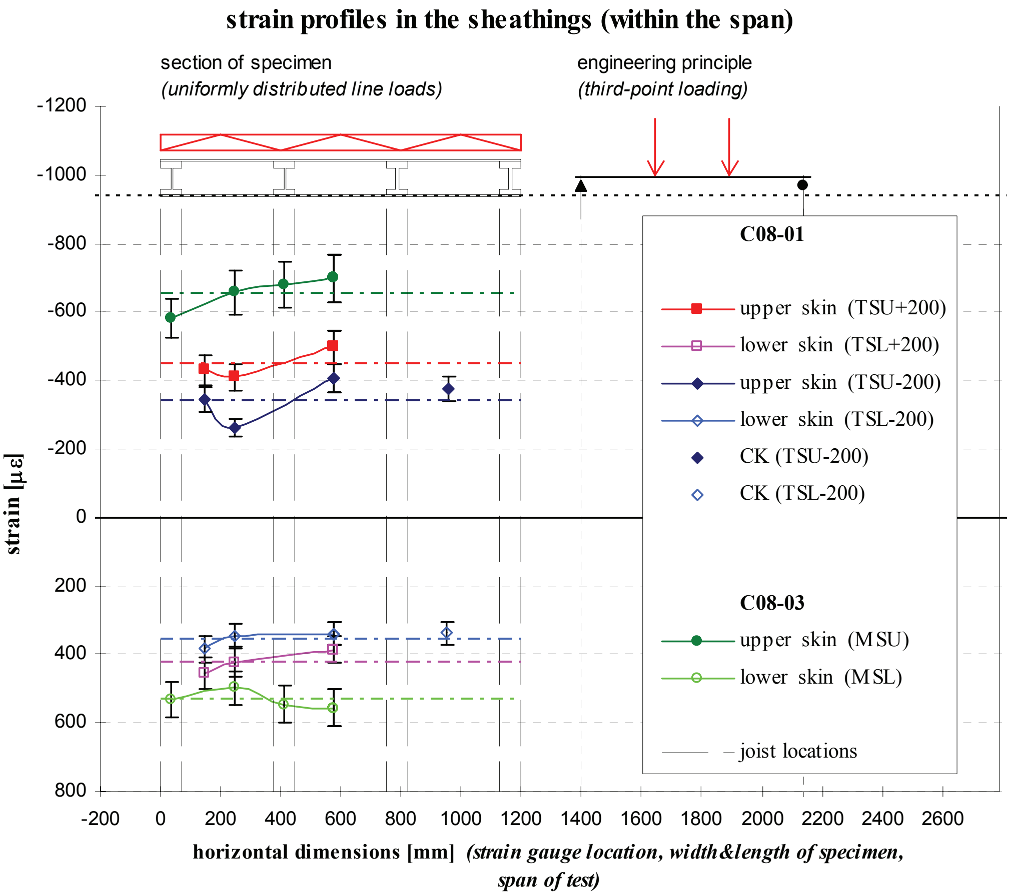


Figure 5. Strain orthogonal strain in the sheathings – continuous sheathings.

The strain distribution also suggests that the idealisation proposed by Amana and Booth [4] can be applied without compromising the safe design of SSP structures. Therefore, design guidelines, such as those found in EC5 [8], can be regarded as reliable.

4.2 ANALYSIS OF THE TRIBUTARY WIDTH – DAMAGED-STATE SPECIMEN

This qualitative analysis focuses on the identification of the contra-distinct pattern, that is, the strain intensity in the portions of the sheathing on the joists and between the joists exhibits significant variations. It is conducted with the test data of a representative specimen, C09-01 (Figure 6).

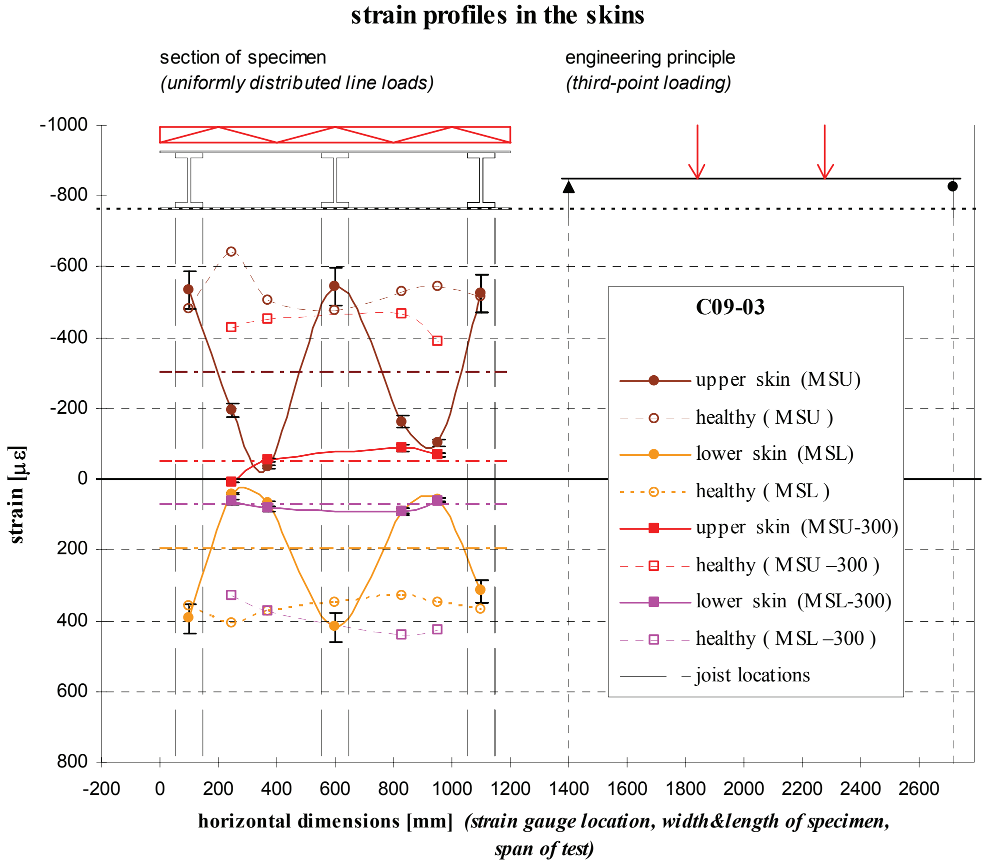
The strain profiles (MSU and MSL) agree very well with the criteria of the contra-distinct pattern – high intensity of strain on the joists whilst the sheathings experience low (quasi zero) intensity of strain between the joists. This also seems to indicate that the portions of the sheathings acting compositely with joists are reduced at the locations of MSU and MSL readings.

Examining MSU–300 and MSL–300 (unfortunately the analysis of the strain pattern is penalised by the absence of measurements on the joists), it may be argued that the readings available point toward a similar pattern to MSU and MSL. Firstly, all four-gauge series are arranged symmetrically about the cut (±150 mm) and, secondly, they exhibit strains of identical intensity in the unsupported portions of the sheathings. It is therefore legitimate to assume that MSU–300, MSL–300, MSU and MSL exhibit similar strain patterns, thus, that MSU–300 and MSL–300 agree with the contra-distinct pattern.

Furthermore, Gerber [1] has also identified that near a support, where the stress in the sheathing is transferred to the joists, the contra-distinct strain pattern is also recognisable. This may indicate that a similar phenomenon occurs near a gap in the sheathing, that is, this pattern suggests that the stress in the sheathing transits through the joists.

The strain distribution observed near a cut also suggests a loss of the structural contribution of the sheathings. That is, the sheathings and joists may no longer be considered as a "fully" composite structure. As a consequence, the design guidelines put forward in EC5 [8] may not be appropriate for the safe design of SSP structures with discontinuities, that is, a safe design is only achievable with a thorough analysis of the structure.

The results of this analysis strongly suggest that discontinuities should be avoided in the sheathing in order to preserve the full benefit of the composite action in the SSP structure. In other words, the sheathing must be manufactured as a continuous skin. This is achieved by structurally splicing the panels of the sheathing and avoiding cuttings.



NOTE: the dashed curves with markers depict the strain profiles of the healthy-state specimen – data calibrated to the load intensity of the specimen in damaged state.

Figure 6. Strain orthogonal strain in the sheathings – discontinuous sheathings.

5. CONCLUDING SUMMARY

This analysis of the tributary width demonstrates that, in SSP structures with continuous sheathing, large portions (quasi the whole) of the sheathing act compositely with the joists. The distinct pattern – quasi uniform strain distribution in the sheathing – has been identified in the laboratory specimens. It is therefore concluded that, in conditions such as or equivalent to those of the laboratory investigation conducted by the first author, a full contribution of the sheathing, as composite flange to the joists, can be considered.

Discontinuities in the sheathing have been identified to deteriorate its structural contribution. The contra-distinct pattern, characterised by peaks of strain on the joists and troughs of strain between the joists, occurred as such in the laboratory specimens in a damaged state. Thus, it is recommended to consider a reduced structural contribution of the sheathing in these circumstances. It is also encouraged to conduct a thorough analysis of the structure with a particular focus for the actual contribution of the sheathing. Alternatively, in order to maintain full composite action and sheathing contribution, the sheathing is manufactured with structural splicing.

Furthermore, this analysis indicates that the EC5 [8] design directives for SSP structures are safe for the conditions of continuous sheathing. This reservation imposes structural splicing of the sheathing. It also indicates that EC5 may not be suitable for SSP systems with discontinuous sheathing. In such state, SSP systems are structurally “weakened” (loss of structural performance) because of the deteriorated composite action [1] and reduced sheathing contribution.

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