TWO-SPAN TESTS FOR SANDWICH PANELS UNDER SIMULATED TEMPERATURE AND EXTERNAL LOAD

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Abstract

Temperature loads have to be incorporated in the design of sandwich panels for building construction and mostly become the decisive load case if the static system is a continuous beam. Typically, a three point bending test is performed to determine the interaction between bending moment and support reaction. This test is commonly known as simulated central support test for which EN 14509 [1] rules the testing procedure. This paper compares the simulated central support test to a new type of two-span test. The new test incorporates simulated temperature and external load. The temperature load was simulated by raising the mid-support in the two-span tests. After raising the mid-support two line loads in each span were applied. The combination of the two load cases, simulated temperature and line loads, corresponded exactly to the conditions in the simulated central support test. All tests failed in the same way, which was wrinkling of the compressed face sheet at mid-support. For wall panels the two-span tests showed similar results to the simulated central support test. For roof panels instead, the two-span tests led to far higher resistance than predicted by the simulated central support test. Obviously, the profiled outer face sheet of the roof panels plays a greater role than expected.

1. Introduction

Sandwich panels for building construction usually consist of a light core of polyurethane foam or mineral wool and two thin face sheets of steel. They are used as building envelope (wall or roof) with the advantage that they are structural member and thermal insulation altogether. The design of sandwich panels incorporates the combination of external loads, such as wind and snow as well as temperature loads whereof the latter play a major role if the system is statically indetermined. The temperature difference for the summer load case varies between 30 K and 55 K in Germany. For the winter load case the difference is −40 K. The bending moment due to temperature difference is normally far higher than the one for snow and wind loads. So in practice, the decisive load case is either temperature load on its own or a combination of temperature and external loads in which the temperature load is the dominant variable action. Depending on the direction of load, the mid-support reaction is either positive or negative. This paper focuses on positive support reactions. They are generated by temperature difference in winter, snow or wind in compression.

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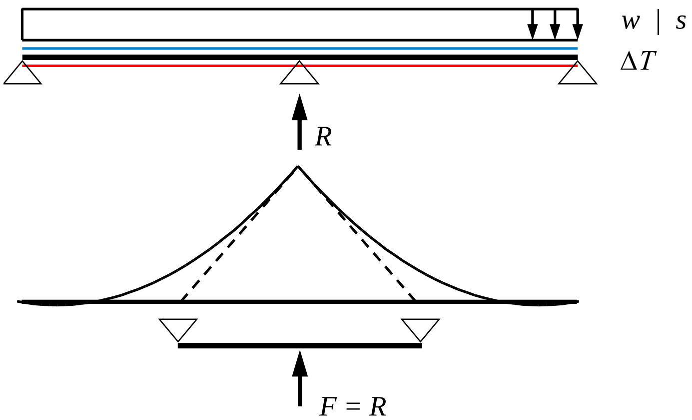

Figure 1. Loading of a two-span panel and the related moment distribution in comparison with the one from the corresponding simulated central support test.

Table 1. Relation between continuous core depth and span in simulated central support test [1].

Continuous core width d_C	Span L
$d_C < 40$ mm	3,0 m
40 mm $< d_C <$ 60 mm	4,0 m
60 mm $< d_C <$ 100 mm	5,0 m
$d_C > 100$ mm	$\geq$ 6,0 m

Two actions work on the inner face sheet at mid-support. On the one hand, the global bending moment stresses the face sheet in compression. On the other hand, the local introduction of the mid-support reaction loads the face sheet perpendicular to the element plane. A three point-bending test simulates these conditions. This test is often called simulated central support test. The European Standard EN 14509 [1] provides the testing procedure which usually leads to the spans listed in table 1. EN 14509 [1] proposes the given values for single span tests. In practice they are also used for simulated central support tests. EN 14509 [1] sets the support width, meaning the width of the central load in the test, to L_s = 60 mm. This value corresponds to the smallest width of cold formed steel sections which often build the support in real conditions. EN 14509 [1] does not include the positive effect if a wider section, e.g. of hot-rolled steel, timber or conrete, provides the real support.

Tests in [2, 3] showed that for small spans and external loading a wider mid-support increases the serviceability load. Theses tests also yielded that the simulated central support test equals the two-span tests acceptably well. But in these tests only external loads were considered. A two-span panel under temperature and wind/snow load leads to a different moment distribution compared to the one out of the simulated central support test (figure 1). So the question arises if a three point bending test is able to simulate the moment distribution under real conditions. Additionally, there is an interest to get to know if a wider mid-support affects the bending resistance again in a positive manner. For these reasons two-span panels were tested

- which combine external loads with simulated temperature loads and
- which include two different support widths, namely 60 mm and 200 mm.

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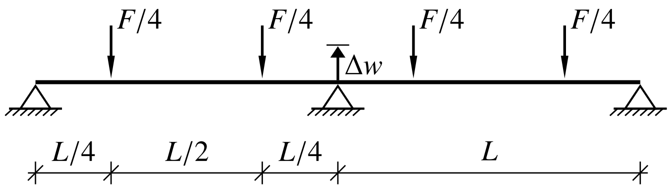

Figure 2. Static system of the two-span test with applied load cases.

Table 2. Overview of test programme.

type of test	L in mm	test number	type of panel	L_s in mm	number of tests
single-span test	3900	W 2	wall	–	3
	3900	R 2	roof	–	3
simulated central support test (SCST)	3900	W 3	wall	60	3
	3900	R 3	roof	60	3
two-span test (2SpT)	2 × 3950	W 9	wall	60	3
	2 × 3950	R 9	roof	60	3
	2 × 3950	W 10	wall	200	3
	2 × 3950	R 10	roof	200	3

Instead of applying a real temperature difference it was preferred to raise the mid-support which facilitated the test execution and rose the precision to achieve the desired load level. A set of two line loads in each span simulated the external load (figure 2).

2. Two-span tests

2.1. Test programme

It was decided to do the simulated central support test first and to adjust the test procedure for the two-span test afterwards. This order implies the advantage that the results of the two-span test become somehow predictable since it is expected that both tests behave fairly similar. As a result the simulated central support test could only be conducted with $L_s = 60$ mm because the total number of panels was limited. So the two-span tests with $L_s = 60$ mm matched the corresponding simulated central support test whereas the test procedure for the two-span tests with $L_s = 200$ mm were adopted from $L_s = 60$ mm. The only change was in width of the mid-support. Table 2 lists the total test programme.

2.2. Testing procedure and test set-up

The load conditions for the simulated central support test and the two-span test must be the same to make both tests comparable. On account of this, two conditions have to be fulfilled. The mid-support reaction and the sandwich moment at mid-support, they both must be equivalent:

$$M_{S,2SpT} \overset{!}{=} M_{S,SCST} \tag{1}$$

$$R_{2SpT} \overset{!}{=} R_{SCST} \tag{2}$$

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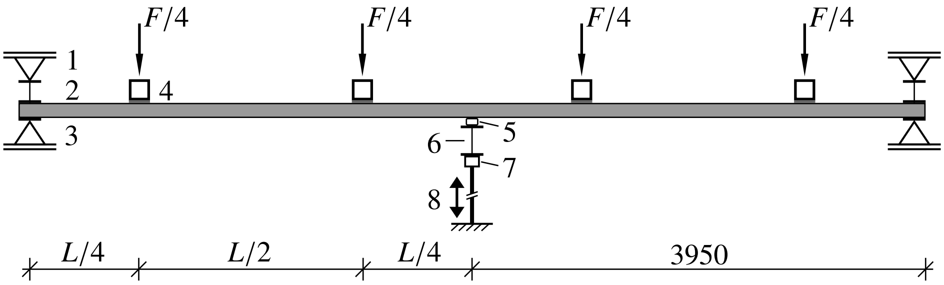

1: Bar Clamp
2: HEA 100
3: Steel Plate over Round Bar
4: QHP 100×10 mm^2 with Lining of Timber/Celluar Rubber
5: RHP $60 \times 40 \times 3$ mm^3 / Plate 200×20 mm^2
6: HEA 140
7: Load Cells
8: Threaded Rod (adujstable in height)

Figure 3. Scheme ot the test set-up for combined loading (external load and mid-support displacement).

Table 3. Mechanical and geometrical properties of tested panels (mean values). Notation according to EN 14509 [1]. Index 1 indicates the outer face sheet, index 2 the inner face sheet. The inner face sheet was in compression during the tests.

	E_{Ct} in N/mm^2	E_{Cc} in N/mm^2	G_C in N/mm^2	σ_{w2} in N/mm^2	t_1 in mm	t_2 in mm	e in mm
wall	4.37	3,81	3.57	175.6	0.51	0.49	38.1
roof	2.68	2,64	2.64	148.2	0.43	0.42	39.1

These two conditions imply that the ratio between the sandwich moment and the support reaction is the same for both types of tests. The external forces and the equivalent mid-support displacement were determined in such a way that the equations (1) and (2) were fulfilled.

Figure 3 shows a sketch of the test set-up. The loading was divided into three steps. At first the mid-support reaction due to self-weight was measured shortly before the test. In the second load step the mid-support was raised by hand to the calculated target value. The external loads were applied in the third and last load step. The load was risen until the first failure at mid-support.

2.3. Test results and discussion

As expected the wall panels and the roof panels with $L_s = 200$ mm failed in wrinkling. Only for the roof panels with $L_s = 60$ mm the failure mode was not as well-defined. It is best described by wrinkling with a slight tendency to delamination of the face sheet. Table 3 lists selected mechanical and geometrical properties of the tested panels. Figures 4 and 5 present the test results as sandwich moment at mid-support over mid-support reaction. The sandwich moment at mid-support was calculated on basis of the measured support reaction using linear (classical) sandwich theory [4–6]. According to EN 14509 [1] the span equalled the centre line of the supports. Widely used design proposals employ the same assumption (e.g. [7, 8]). The curves for the sandwich moment in Figures 4 and 5 consist of three parts which correspond to the order of loading: self-weight first, then mid-support displacement and finally the line loads in each span.

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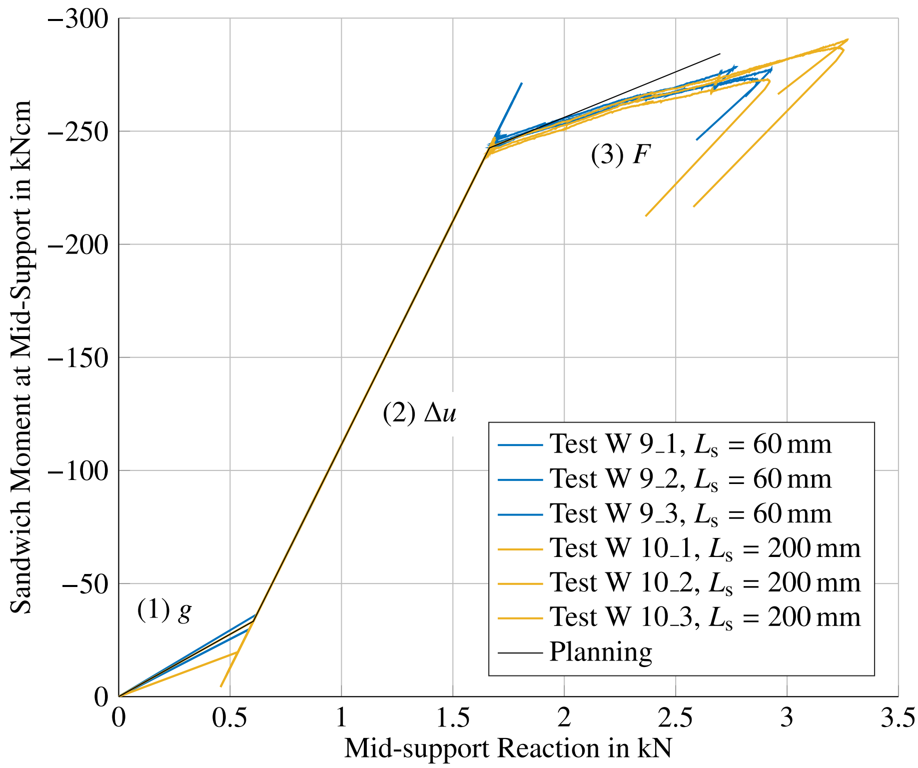

Figure 4. Test results at mid-support for wall panels.

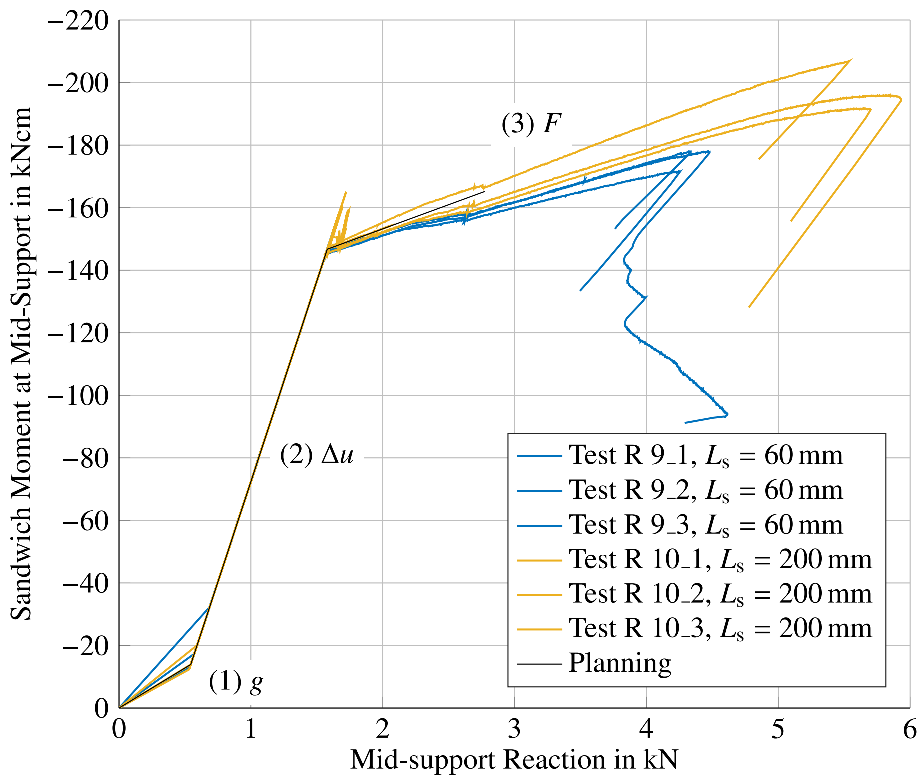

Figure 5. Test results at mid-support for roof panels.

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For simplification the planned (theoretical) loading path is shown for only one experiment in each graph. Except for the first load step (self-weight), the planning is the same for all experiments. The ending point of the theoretical line matches exactly the sandwich moment and the mid-support reaction in the simulated central support test with $L_s = 60$ mm at time of failure. This implies that the two-span tests with $L_s = 60$ mm would perfectly equal the simulated central support test if they failed exactly at this point. For the two-span tests with $L_s = 200$ mm no such point exists since the corresponding simulated central support tests could not be done beforehand. These tests would had been necessary to determine a target point because they influence the loading path in the two-span tests. Hence, the tests with $L_s =$ 200 mm only allow to rate the gain in performance compared to the tests with $L_s = 60$ mm. But they automatically imply another ratio of sandwich moment to mid-support reaction.

Figure 4 shows that the simulated central support test is actually able to simulate a real two-span condition for wall panels. The target value of the sandwich moment is almost reached and the one of the mid-support is even slightly exceeded. The gain in performance for the wider mid-support comes into notice by the increase in the ultimate mid-support reaction which appears for two of the three tests. It originates from the testing procedure that the higher perfomance shows essentially up in terms of mid-support reaction but not of sandwich moment.

For roof panels the test results are totally different (see figure 5). The simulated central support test clearly underestimates the real two-span conditions. Due to the testing procedure the difference can be primarily seen in the higher mid-support reaction. The wider mid-support additionally leads to an increase in the sandwich moment because the ultimate mid-support reaction is approximately doubled compared to the simulated central support test with $L_s = 60$ mm.

The difference between wall and roof panels was unexpected. The geometry for both types of panels is very similar (compare table 3) and the difference in core properties resembles the normal variation for sandwich panels. So the only major difference lies in the profiling of the outer surface. Obviously, the profiled outer face sheet helps to increase the load bearing capacity of the inner surface.

3. Conclusion and Outlook

For wall panels, the simulated central support test is able to simulate the real conditions in a two-span test. The tests showed almost no difference. For roof panels the simulated central support test can be used as well, but the tests revealed that a two-span set-up offers large reserves in bearing capacity. So in this case the simulated central support test is a rather conservative testing method. The tests also showed that a wider mid-support may increase the wrinkling load whereas its influence for roof panels is more pronounced. All the results lead to the conclusion that the profiled outer face sheet of the roof panels plays a major role for the local bearing capacity of the inner face sheet.

Further research is needed to look precisely at this interaction. Additionally, it is planned to evaluate the test results for a slightly different static system. According to EN 14509 [1], it was assumed that the span equals the distance between the centre lines of the supports. Current research at the department of steel structures suggests to simulate a mid-support by two pinned supports at a distance of the support width. For $L_s = 60$ mm the influence is probably negligible, but for a wider mid-support the difference might be of interest.

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