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Diaphragm shear strength and stiffness of aluminum roof panel assemblies

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ABSTRACT

A diaphragm is an assembly of planar structural elements interconnected to each other to provide in-plane bracing system and transmit in-plane forces. The diaphragm geometry, supporting frame, type of the panel profiles, the way the panels are attached to each other and to the diaphragm frame govern the overall behavior of diaphragm systems. Full scale testing is the best way to understand the overall behavior and determine the strength and stiffness of diaphragm systems.

This paper is a result of experimental and analytical studies on aluminum roof panel assemblies. The main purpose is to check the applicability of Metal Construction Association's (MCA) "Primer on Diaphragm Design" for the strength and stiffness equations when applied over a range of panel depths, thicknesses and profiles. Five full scale cantilever tests were conducted at Virginia Tech, Blacksburg, Virginia. The tests were conducted in accordance with the AISI "Cantilever Test Method for Cold-Formed Steel Diaphragms".

While the diaphragm shear stiffness development is similar for both MCA and Steel Deck Institute's (SDI) "Diaphragm Design Manual", the only difference is the panel edge term (K). The results of this study show remarkably narrow scatter in tested-to-calculated strength ratios. The tested-to-calculated stiffness ratios compare very well, supporting the proposed use of panel edge term ($K=2/3$) for aluminum diaphragms. The results indicate that the panel thickness limit can be raised safely to 1.27 mm (0.050 in.) for MCA procedures. The test data further indicate that the MCA strength and stiffness formulations work well for panels with depths through 101.6 mm (4 in.).

1. Introduction

The planar structural elements are interconnected to each other through a structural diaphragm. The main elements of a diaphragm are the supporting frame, the panels and the interconnecting fasteners. Per the terminology, the panels are connected to the supporting frame by "structural connectors" and they are connected to each other by "side-lap (stitch) connectors". Diaphragms resist the planar shear load in their own plane and transfer the load by providing an in-plane bracing system [1]. The diaphragm"s planar forces can be due to wind, earthquake or any other type of loading. The diaphragm action helps the planar structural system act as a single unit by developing in-plane shear strength and stiffness [2]. In addition, the diaphragm action provides the structure with stability under applied loads [3,4].

The overall behavior of diaphragm systems is governed by diaphragm geometry, supporting frame, type of the panel profiles, the way the panels are attached to each other and to the diaphragm frame. Therefore, the strength of the connecting elements, local buckling of the panel profiles and global plate-like buckling of the entire diaphragm assembly can limit the shear strength of the diaphragm. The best way to understand the overall behavior and determine the strength and stiffness of diaphragm systems is full scale testing. A large number of studies were conducted in the world [5–30], over the decades which resulted in the development of strength, stiffness and connection capacity equations and design procedures. "A Primer on Diaphragm Design" by Metal Construction Association (MCA) [31] and "Diaphragm Design Manual" by Steel Deck Institute (SDI) [32] are products of most of these efforts. The evolution of the calculation procedure, which formally appeared in the first edition of the SDI Diaphragm Design Manual, are represented in the MCA [31] and the SDI [32] documents.

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Further development and formalization of the procedures now appear in the North American Standard for the Design of Profiled Steel Diaphragm Panels per AISI 2013 [33].

The diaphragm shear stiffness development is similar for both MCA and SDI calculations. The full development of the shear stiffness equations can be found in the SDI Diaphragm Design Manual [32]. Diaphragm stiffness is a function of the in-plane stiffness of the corrugated panels, the stiffness of fasteners placed through the panels (both structural and sidelap) and the warping behavior of the corrugated panels. The diaphragm behavior is mathematically complicated with the reference documents [31,32] providing a procedure suitable for design calculations. The slight difference is the panel edge term, “K” that is included for aluminum panels. Most diaphragms have their stiffness controlled by structural connectors and panel sidelaps. As a result, the panel edge conditions dictate both strength and stiffness of the diaphragms. For aluminum panels, the general stiffness formula is modified by the panel edge term, $K=2/3$, when using the MCA Primer on Diaphragm Design. This empirical modification was included in the MCA approach based on a review of test data. The use of $K=2/3$ is to be checked by the study shown in this manuscript, along with other properties.

Five full scale tests were conducted to evaluate the applicability of MCA”s “Primer on Diaphragm Design” for aluminum panel assemblies over a wider range of panel geometries. The tests were conducted in accordance with the AISI “Cantilever Test Method for Cold-Formed Steel Diaphragms” per AISI 1996 [34] and AISI 2008 [35], at the Thomas M. Murray Structures Laboratory of Virginia Polytechnic Institute and State University, Blacksburg, Virginia. The test program was sponsored by the Metal Construction Association.

The full scale cantilever tests were specifically designed for checking and verification of MCA strength and stiffness equations when applied over a range of panel depths and profiles. The diaphragm shear strength and stiffness for five panel cross sections were extensively studied.

The five aluminum panels are:

- Panel 1 with thickness; 1.016 mm (0.04 in.).
- Panels 2–3–4 with thicknesses; 0.813 mm (0.032 in.), 1.016 mm (0.040 in.) and 1.27 mm (0.050 in.) respectively.
- Panel 5 with thickness; 0.457 mm (0.018 in.).

Panels 1-to-4 are HS35-H36 aluminum alloy material (5052-H36) whereas Panel 5 section is a HS35-H38 aluminum alloy material (5052-H38). Both 5052-H36 and 5052-H38 alloys are variants of 5052 aluminum (AlMg2.5, 3.3523, A95052). They share alloy composition and several physical properties, however, they have slightly different mechanical properties as a result of different processing. The panel cross sections are illustrated in Fig. 1.

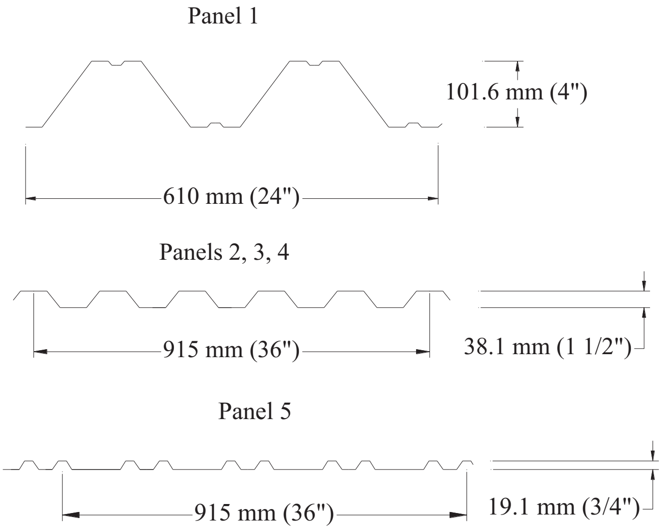

Fig. 1. Tested panel profiles.

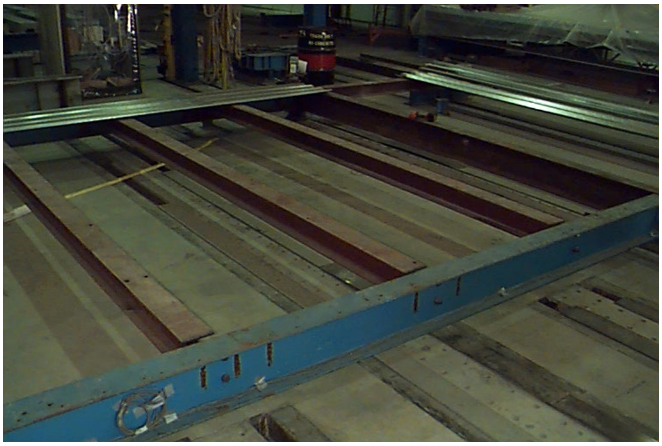

Fig. 2. Bare diaphragm test frame.

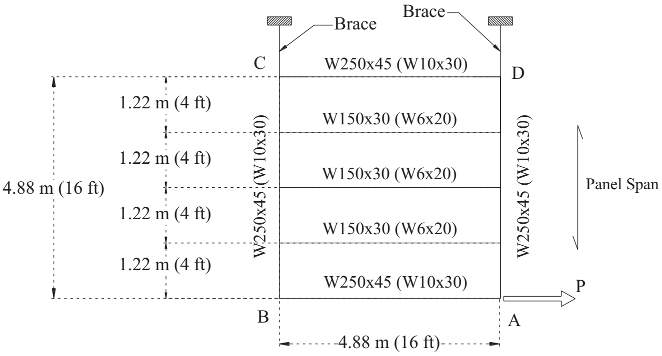

Fig. 3. Diaphragm test setup- plan view.

2. Experimental study

2.1. Test setup

The cantilever diaphragm test reaction frame, as shown in Figs. 2 and 3, was constructed of seven H-shaped sections. Four W250 × 45 Metric (W10 × 30 US Customary) sections were used as perimeter members. Three W150 × 30 Metric (W6 × 20 US Customary) sections were used as filler members for the test setups except the Panel 1 assembly for which only one filler beam was used. Nominal plan dimensions for the diaphragm frame were 4.88 m × 4.88 m (16 ft × 16 ft). The perimeter members were connected with a single-angle at corner B, a double angle at corner C, and a T-section at corner D. A pin was used to connect the frame members at corner A. Member CD was attached to the reaction floor by using pinned base assemblies at locations C and D. In addition, the web was braced at points C and D to minimize rolling of the member, as illustrated in Fig. 3. Member AB was supported by rollers at locations A and B. An additional roller assembly was positioned at A on the bottom flange to resist uplift of the member, as illustrated in Fig. 4.

The diaphragm deck panels were connected to the frame by “1/4–14 × 1 in.” structural connectors with 6.35 mm (1/4 in.) diameter (14 threads-per-inch, 1 in. long connectors) while they were