Sheet Steel Facts 9

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Alternative Design Methods for Steel Deck Diaphragms

Introduction

Cold formed steel diaphragms are constructed from profiled steel sheets or panels fastened together and to framing members to resist in-plane shear forces.

Knowledge of the diaphragm capabilities of roofs, walls and floors can be a great advantage to the structural engineer in designing buildings to resist forces caused by wind, seismic action and other lateral loads. Roof and wall panels used for the enclosure are customarily designed only for transfer of the normal components of surface loads into the structural framework. The in-plane shear resistance of such systems may not have been fully utilized because there is a lack of generally accepted diaphragm design data and procedures for all available panel configurations.

Governing Standards

In Canada there is no standard governing the design of steel deck diaphragms. The designer must rely on currently accepted design procedures, rational analysis or testing. Some manufacturers of steel deck publish tables of diaphragm design values for their products which may be used by the designer. The problem arises, however, if a designer is faced with an assembly that is not typical and for which there are no published values.

Analytical Procedures

Various procedures for diaphragm analysis and design have developed over the past four decades. These procedures vary in complexity and in the extent to which testing was used in their formulation. The basic aspects of diaphragm behaviour that should be considered in an analytical procedure are strength and stiffness. Strength is usually determined based on connection failures, however, buckling failures must also be considered for the shallow cladding profiles.

All analytical methods include empirical data developed from a testing program as a basis for some aspects of their formulation.

The various published analytical methods range in complexity from relatively simple mathematical equations to complex, nonlinear, finite element solutions. The most commonly used methods in Canada are described here.

CSSBI/Tri-Services Method

The “Tri-Services” method[1] was developed by S.B. Barnes and Associates and is based on a series of full scale tests from which empirical equations for both strength and stiffness were developed. The CSSBI adopted this method as the basis for its first bulletin in 1972 and the current edition B13-91, “Design of Steel Deck Diaphragms”[2].

Since this method is empirically based, it does not indicate the failure mode of the diaphragm and is limited in the type of fasteners that can be included. Also, no explicit factor of safety has been stated, although a value of 2.5 has typically been assumed.

The following limitations apply to this method:

a. Connections of the deck to the supporting structure must be welded with 12mm (1/2 in) minimum effective diameter welds.
b. Side lap connections between sheets must be button punched or seam welded.
c. Sheet thickness must be at least 0.76 mm (0.030 in, 22 gauge). The maximum thickness is 1.52 mm (0.060 in, 16 gauge).
d. Each deck unit must be attached to the framing member by at least two welds.
e. Side lap attachments have a maximum spacing of 0.9 m (3 ft.).
f. The original tests were based only on horizontal assemblies.

This method has the following advantages:

a. The strength and stiffness of the individual deck sheets can be tabulated. This allows a deck manufacturer to publish tables for each deck profile.
b. It is independent of deck orientation.
c. It can also be used for concrete filled assemblies.
d. This is a hand-calculation method that can be easily computerized.

The Tri-Services method has become the most popular method used in Canada in part because it has been promoted by the CSSBI, but also because it fits the standard construction practices in Canada. Tests conducted in Canada over the years have confirmed the validity of this method for welded and button-punched diaphragms.

Steel Deck Institute (SDI) Method

The SDI method was developed by Dr. L.D. Luttrell and is based on analytical work and tests conducted at West Virginia University. The method is easy to use and is considered as a "hand calculation" method. The first edition of the SDI method was published in 1981 and the current second edition[3] was published in 1987.

Dr. Luttrell determined that the purlin spacing, deck thickness, fastener types and fastener arrangements have the strongest influence on diaphragm behaviour. Most common diaphragms with relatively few fasteners do not fail by buckling but fail either due to shearing of the fasteners, localized bearing failure of the sheet around the fasteners, or local shear buckling.

The ultimate strength of the diaphragm is limited by any one of three possible failure modes:

a. Fastener failure in edge members.
b. Fastener failure at interior side laps.
c. Failure of the fasteners across the panel ends.

This method is flexible because it is an analytical method that has been confirmed by test and allows the tabulation of strength and stiffness values. Any type of fastener can be included, or mixed types, if the strength and stiffness characteristics are known. It is used extensively in the United States.

European Design Recommendations

The European recommendations for the stress skin design of steel structures is published by the European Convention for Construction Steel Work[4]. The general approach used is well described by J.M. Davies and E.R. Bryan in their book "Manual of Stress Skin Diaphragm Design"[5].

This procedure may also be considered as a hand calculation method. It employs a detailed and understandable approach to the diaphragm design by examining every individual aspect of diaphragm strength and stiffness. In this way the designer can readily see which aspect of the diaphragm is most flexible and note any "weak links in the chain".

The method has been developed primarily for use with mechanical fasteners, although any type of connection can be included if its strength and stiffness characteristics are know. The sheet products analyzed in this reference are light gauge products more common to cladding than structural deck. This is an advantage to designers trying to determine diaphragm capacities of wall cladding, however, it increases the work needed for typical roof deck construction.

The method is very comprehensive and the strength determination is based on the least strength of: seam failure, sheet/shear connector failure, overall shear buckling of the sheet, failure in the sheet/purlin fasteners, and compression failure in the edge member. Diaphragm flexibility is dependent on the profile distortion, axial strain in edge members, shear strain and fastener stiffness.

A disadvantage of this method is that it is dependent on the orientation of the profile. The designer must calculate the diaphragm capacity for each project and cannot readily take advantage of "generic" tables such as are available with the Tri-Services or SDI methods.

Testing

Testing is always an option for determining the capacity of a diaphragm assembly. The American Iron and Steel Institute has published a standard test method for steel deck diaphragms[6], and there is the ASTM Specification E455[7].

Finite Element Analysis

There are non-linear finite elements analysis approaches to the modelling of shear diaphragm behaviour as well as simplified analysis procedures. In general these are analysis tools used to do parametric studies, look at the effects of openings, determine individual fastener forces, or any other specific task. The amount of time required to set up the analysis makes it impractical as a design tool except in unique circumstances.

Summary

The Tri-Services and SDI methods are tried and proven design methods for the majority of deck configurations in North America. The advantages of using the diaphragm strength should not be neglected.

For More Information

For more information on sheet steel building products, or to order any CSSBI publications, contact the CSSBI at the address shown below.

References

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