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Wind uplift and roofs : mechanically attached membrane study

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Designing Better Mechanically Attached Flexible Membrane Roofs

By Bas A. Baskaran, PhD, P.Eng

For several years, the National Research Council's (NRC's) Institute for Research in Construction (IRC) has been managing the Special Interest Group for Dynamic Evaluation of Roofing Systems (SIGDERS)—a consortium of manufacturers, building owners, trade associations, and researchers.¹

SIGDERS has significantly advanced the knowledge for the testing and design of mechanically attached flexible membrane roofs. These types of assemblies, composed of flexible sheets (the waterproofing component) and mechanical attachments to resist wind uplift, are used on more than 30 per cent of North American commercial buildings. They respond to wind loading differently than other roof systems. Wind-induced suction repeatedly lifts the membrane (Figure 1) between the attachments and causes elongation and billowing. This can lead to fatigue of the membrane, the fasteners, the substrate below, and the fastener/deck connection. To avoid wind-induced failure of the roof system, roof designs need to ensure the resistance of each link is greater than the total wind uplift force (Figure 2).

The design of flexible membrane roofs should consider the following:

- site's wind climate and building aerodynamics;
- desired reliability of the roof assembly—buildings in high wind load locations and/or structures containing critical operations or expensive equipment (*e.g.* hospitals and computer centres) can require a higher level of reliability;
- deck, insulation, membrane, fastener spacing and strength, and other assembly components; and
- attachment of the edge flashing or coping, and these components' resistance to lifting and peeling.

Wind uplift calculation and resistance evaluation

Determining design wind loads is the first step for designing a roof assembly. Wind loads on buildings are determined in accordance with provincial building codes, which use the 2005 *National Building Code of Canada (NBC)* as the model code. The reference dynamic pressure for roof covering loads is based on a mean recurrence interval of 50 years. *NBC's* wind load calculation procedure for roof coverings can be summarized in six steps:

1. Calculation of dynamic pressure.
2. Definition of the corner zone.
3. Calculation of external wind pressure component.
4. Calculation of internal wind pressure component.
5. Calculation of net wind pressure.
6. Development of the loading diagram.

The resistance of the roof assembly to wind uplift is a function of the components used (*e.g.* membrane, seams, fasteners, deck) and their arrangement. Roof system component manufacturers provide design resistance values for their systems based on uplift testing. It is critical these test methods offer a meaningful measure of the system's uplift

performance. To satisfy industry demand for test methods that better simulate actual in-service conditions, SIGDERS developed a new method, which:

- achieves failure modes that occur under real conditions;
- is easier to apply in the laboratory than existing tests;
- allows for variation in roof design;
- produces results quickly; and
- conforms to local standards.

The SIGDERS dynamic testing protocol has five rating levels (*i.e.* A through E), with each consisting of eight load sequences with different pressure ranges. Testing begins at level A; if the roof passes A, it advances to B. Based on the SIGDERS test protocol, a national standard, Canadian Standards Association (CSA) A 123.21, *Standard Test Method for the Dynamic Wind Uplift Resistance of Mechanically Attached Membrane Roofing Systems*, was issued in 2004.

Prior to the introduction of CSA A 123.21, there were two static test standards used in North America to assess wind uplift performance of membrane roof systems (both were based on static testing):

- Factory Mutual Global (FM) 4470, *Class I Roof Covers*; and
- Underwriters Laboratories (UL) 580, *Test for Uplift Resistance of Roof Assemblies*.

For design purposes, the sustained resistance an assembly achieves in either static or dynamic testing must be reduced by a safety factor, as follows:

- allowable design load = test resistance divide by safety factor; or
- required test resistance = allowable design load x safety factor.

The safety factor is intended to account for the following (within reasonable limits):

- variable material strength of the roofing assembly components;
- variability in construction quality; and
- actual wind speed exceeding design values.

Roof designs should be based on a minimum safety factor of 1.5 for systems tested under dynamic conditions. The higher the safety factor is, the greater reserve strength there is to avoid damage during high wind events. During the design stage, it is necessary to correlate the design load with the resistance. For the roof to remain intact, the resistance must always be higher than the design load.

The performance of a roof system depends on the component-to-component resistance to wind uplift. All resistance links must remain connected for the roof system to be durable and remain in place (Figure 2). Failure occurs when the wind uplift force is greater than the resistance of any one of the links between membrane, seam, insulation, barrier, plates, fasteners, or deck. For example, roof failure can be initiated when a fastener pulls out from the deck, even though the membrane and its seams remain in good condition. Failure can also occur when a seam opens.

Design of components

Communication between design professionals is crucial. Structural engineers responsible for the area below the roof deck and designers of the roof assembly must interact to

ensure a continuous load path through the roof system and supporting structure exist. As previously mentioned, for the roof to remain intact, the resistance should always be higher than the design load (Figure 3).

Membrane

Certain membrane properties (*e.g.* tensile strength and tear resistance) influence the roof system's wind uplift performance. The membrane can also tear and pull out from underneath the fastener plate (or batten) because of a lack of clamping force. This failure mode is due to inadequate fastener plate clamping force and results in membrane tearing at the fastener shank. Loss of clamping force can be caused by:

- insulation creep (*i.e.* the insulation relaxes after fastener applications);
- inadequate compression resistance of the insulation to prevent overturning of the fastener plate/batten (Figure 4);
- insulation shrinkage;
- fastener plate/batten deformation;
- fastener back-out; and
- localized deformation (steel decks) in the vicinity of the fastener.

Seams

There are two basic types of seams used for mechanically attached flexible membrane roofs. The asymmetrical seam is the most common arrangement for thermoplastic membranes (Figure 5). Although such a seam can still be designed successfully, wind loading causes greater stress to this type than to its symmetrical counterpart.

The symmetrical seam substantially reduces force eccentricity compared to asymmetrical designs because of a reduction of the forces attempting to overturn the fastener plate (or batten) and rock the fastener shank (Figure 6).

Fastener plates and batten bars

Fastener plates and batten bars maintain a clamping force on the membrane to deter tearing and slippage from under the plate. Fastener plates with barbs provide increased resistance to membrane slippage (Figure 7). Some fastener plate designs provide resistance to 'pop-up,' which occurs when the insulation compresses or the fastener backs out and risks puncturing of the membrane. If the plate is an anti-pop-up type, membrane puncture is unlikely, but plate compression can still occur, making the membrane susceptible to tearing at fastening points.

Batten bars distribute loads by providing a clamping force to deter tearing and slippage of the membrane. They need to be suitably robust to withstand repeated dynamic loading from high wind events without deforming.

Fasteners

The membrane attachment method significantly influences a mechanically attached roof's wind uplift performance, with fastener thread designs playing a vital role in resistance. Anti-back-out fasteners are recommended because of their thread design, which reduces the potential for back-out.

The orientation of the fastener rows with respect to the deck flanges affects the connection of the deck to the supporting beam/joists. If the membrane fastener rows are

perpendicular to the flanges, the deck/support attachment loads are reduced. Therefore, fastener rows perpendicular to the deck flanges are recommended (Figure 8).

Insulation and cover boards

The control of heat movement through a roof system depends almost exclusively on the insulation, which also has an important role in the assembly's wind uplift performance. While many different types of thermal insulating materials are available, plastic (*e.g.* polyisocyanurate [polyiso]) insulation is used for the majority of mechanically attached flexible membrane roofs.

Thicker insulation requires a longer fastener shank. This can apply a greater rocking force; if this force is sufficient enough to crush the insulation, the rocking of the fastener results in a reduction of the plate's clamping force. The fastener's horizontal rocking movement is reduced when an air/vapour barrier is installed as part of the roof assembly because it distributes the load. When no barrier is used, insulation thickness has minimal effect on the wind uplift rating of mechanically attached systems.

Cover boards provide several benefits, including:

- protecting the insulation from mechanical damage caused by traffic loads;
- preventing the fastener plates from causing localized crushing of the insulation during high winds;
- providing some protection for heat-sensitive insulation boards during torch applications;
- reducing the risk of problems from condensation within the roof assembly;
- protecting the insulation from solvent degradation;
- providing a moisture buffer between the insulation and the membrane; and
- improving fire resistance.

Air/vapour barriers

Air barriers limit airflow into the roof system, which reduces energy losses in the assembly. They can reduce membrane flutter and should be used wherever moderate winds are frequent (*e.g.* St. John's, Newfoundland). Air barriers are commonly constructed with sheet materials, such as polyethylene. (A two-ply built-up or a one-ply modified bitumen [mod-bit] sheet can also be used.) When sheet products are used, they are applied directly over the deck. The joints of polyethylene sheets are sealed with tape or sealant before insulation/cover boards are placed atop and mechanically fastened to the deck. This means the air barrier assembly (insulation boards, fasteners, and other components above the vapour barrier) must be designed to resist 100 per cent of the design uplift load (adjusted for safety factor).

While air barriers have many benefits, they can make it more difficult to detect leaks. Hence, a small opening in the roof membrane can go unnoticed for quite a while, resulting in a large area of wet roof insulation.

Deck

The deck and the deck attachment are essential features of mechanically attached flexible membrane roof systems. Plywood, wood, plank, concrete, or steel (the most commonly used) are recommended for use on roofs with flexible membranes. For roofs with a very

high design uplift load, a thicker (*i.e.* higher grade) deck and stronger fasteners or denser patterns should be specified to give added resistance.

The deck attachment of the supporting structure must resist the design uplift loads (adjusted for the safety factor). It is desirable to use short membrane fasteners that engage the top of the flange of the deck to reduce the fastener's moment arm.

However, when there are multiple layers of insulation or tapered insulation, or if the roof is being recovered, limiting attachment to the top flange can be time consuming and difficult compared to using fasteners long enough to engage the bottom flange. In this situation, it is better to increase the fastener density.

Conclusion

The successful design and construction of mechanically attached flexible membrane roofs is a factor of calculating wind forces and ensuring the links between the roof elements are capable of resisting them. For the membrane, this means selecting a material adequately tested using dynamic loadings simulating in-service conditions. For more information, SIGDERS' *A Guide for the Wind Design of Mechanically Attached Flexible Membrane Roofs* should be consulted.²

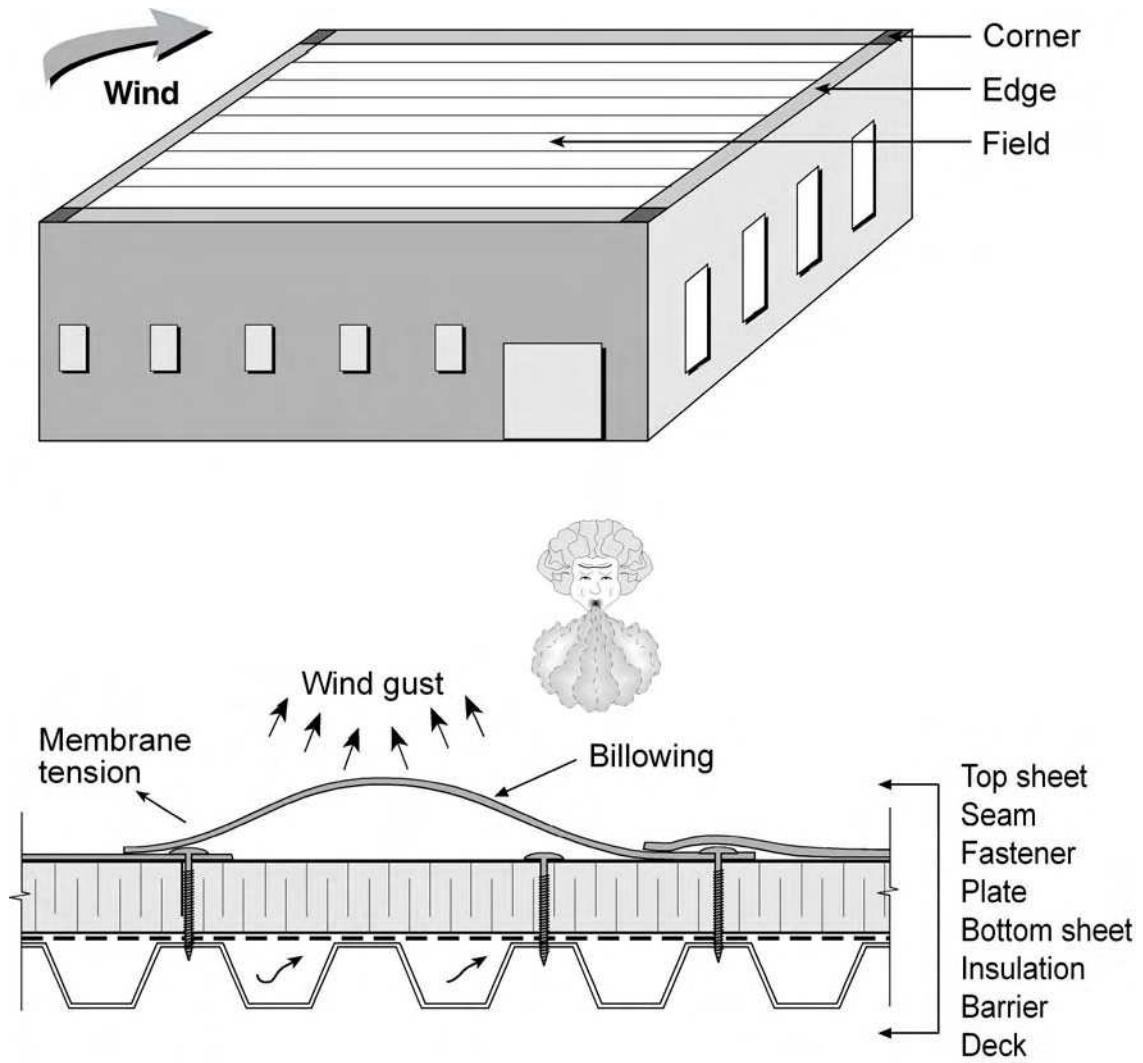
Notes

¹ For more information on SIGDERS, visit irc.nrc-cnrc.gc.ca/bes/prsi/sigders_e.html.

² Visit <http://www.nrc-cnrc.gc.ca/virtualstore> and select 'NRC Construction Publications.'

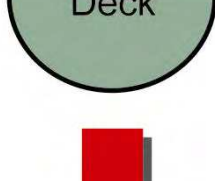
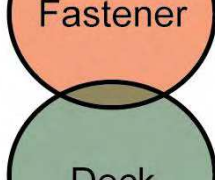
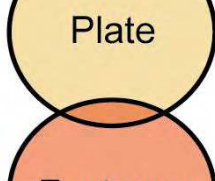
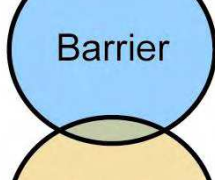
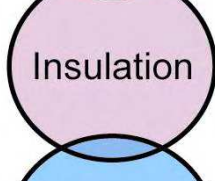
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All figures courtesy Institute for Research in Construction



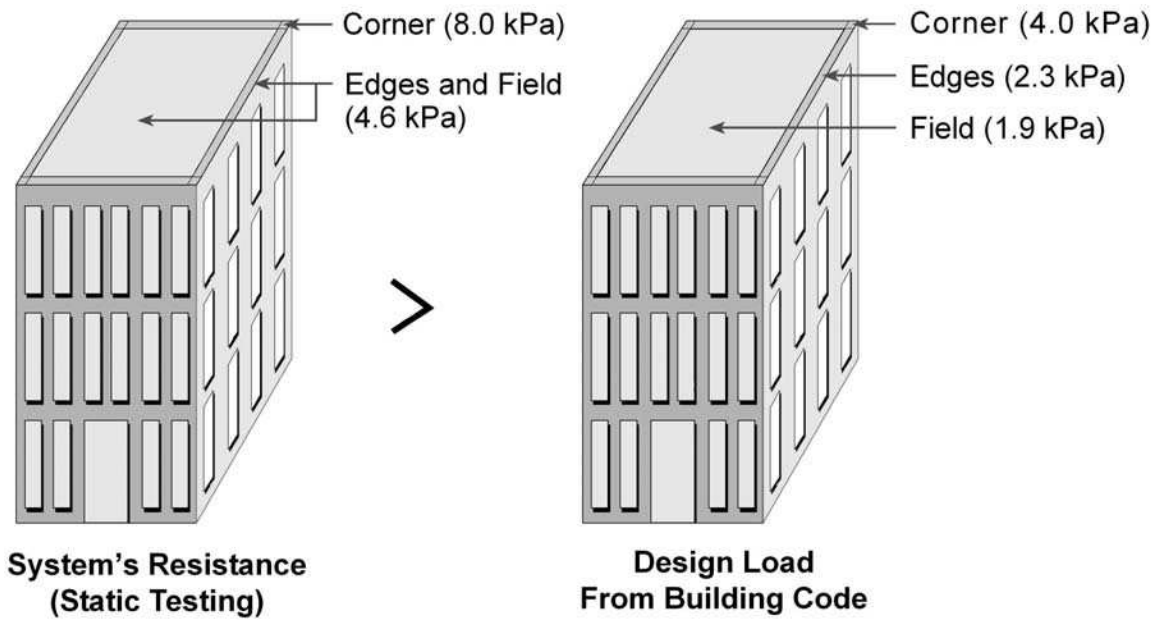
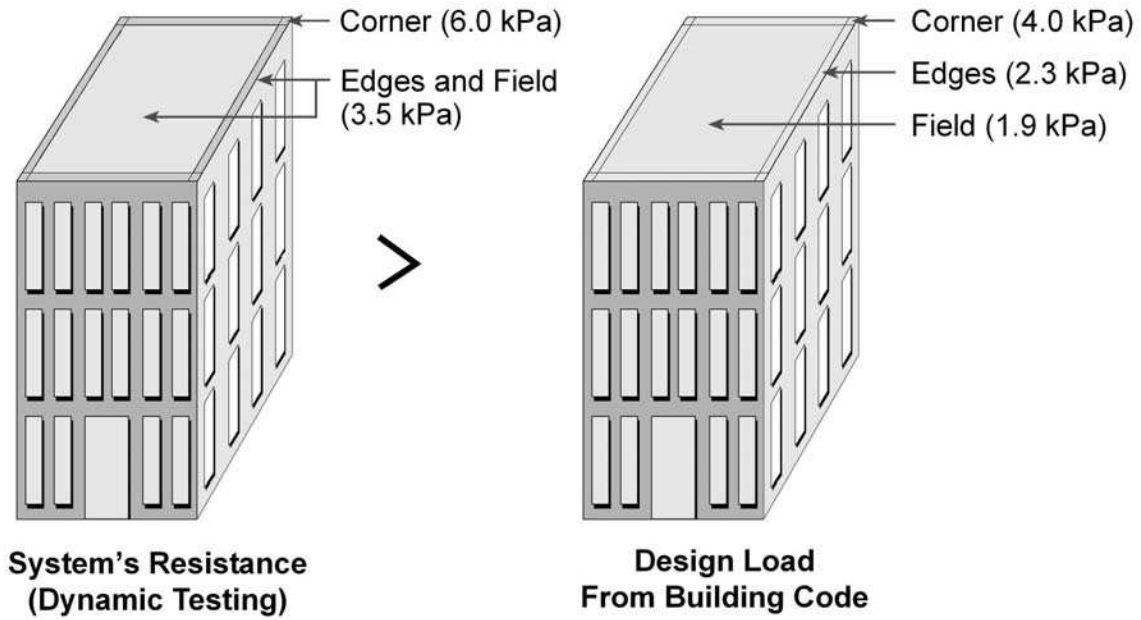
Wind effects on mechanically attached roofing systems.

Wind uplift force



Resistance

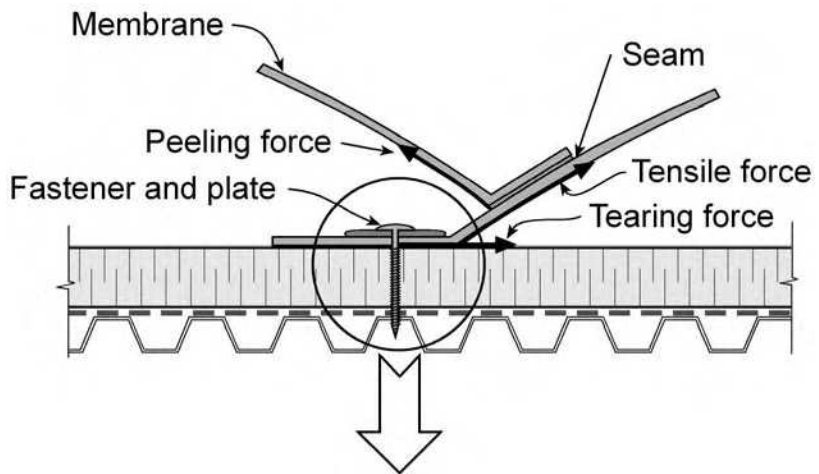
Resistance links of a mechanically attached roofing system.



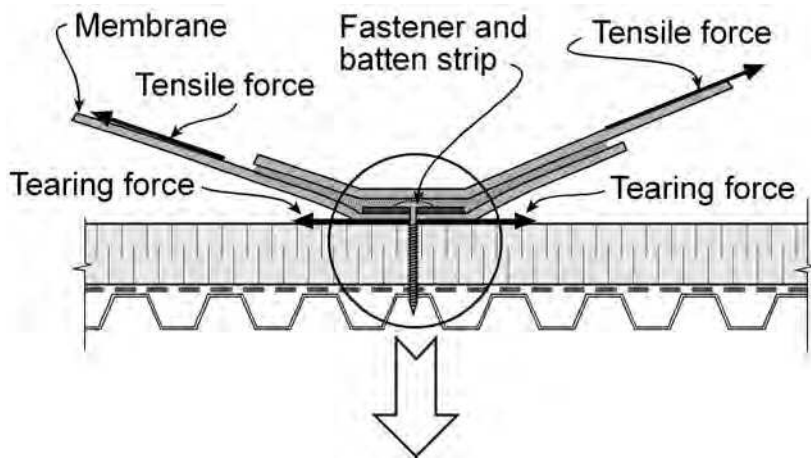
The resistance of the roof must always be greater than the design loads.



Membrane tear underneath the fastener plate due to lack of clamping force.



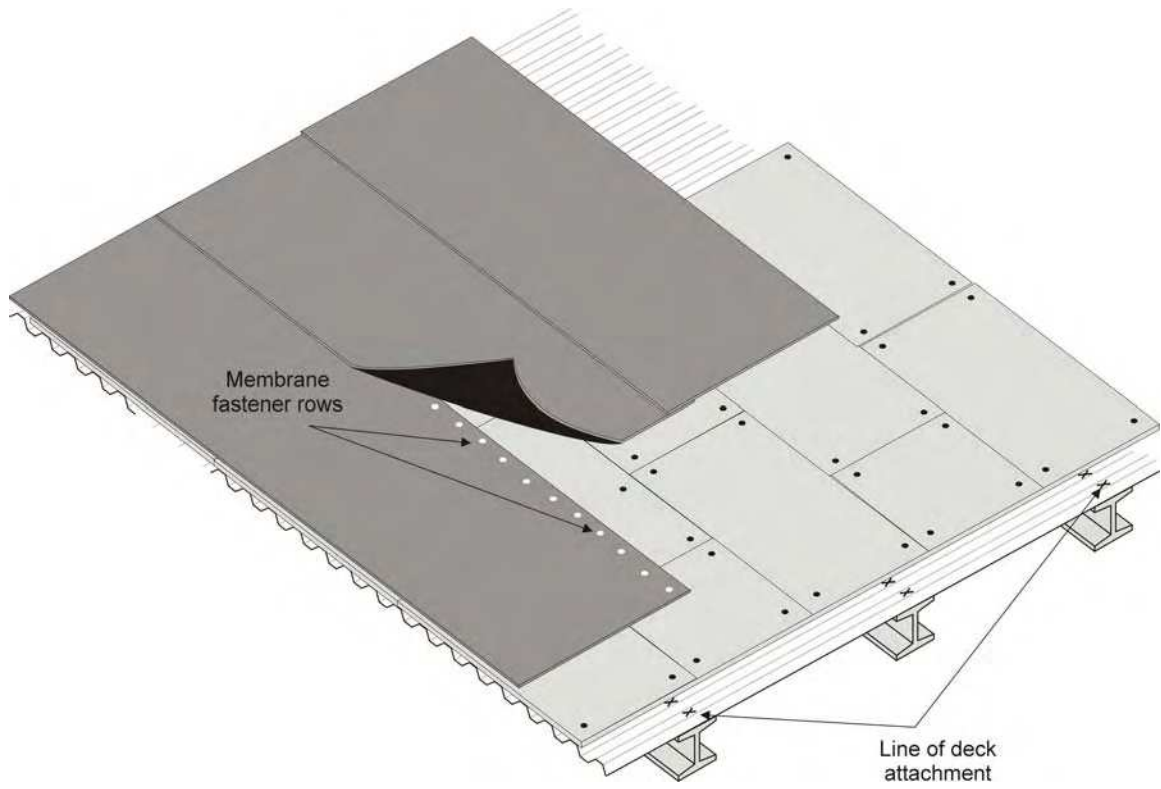
Asymmetrical seam.



Symmetrical seam (for a thermoset membrane).



Typical membrane fastener plates.



Influence area as a function of fastener row orientation – membrane fastener rows are perpendicular to the deck flanges.



The above photo illustrates the application of cap sheet torching on a two-ply modified bituminous system.



This photo depicts the mechanical attachment of a modified bituminous (mod-bit) system