Dynamic Building Envelope Closure Systems

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ABSTRACT

Dynamic building envelope closure systems, regardless of structure size, can be required to provide a reliable sealing system for expansion joints between building elements. These closures are critical to the performance of structures' environments due to design, materials, and codes. Successful integration and coordination of all components is required to ensure excellence.

Solutions for problems with simple and complex transitions that are encountered will be given. Secondary closures, insulated and fire-rated systems, and Building Information Modeling (BIM) will be examined. It will be shown how use of explicit details and specifications developed prior to the bidding stage can lead to successful results.

SPEAKERS

Douglas Pearmain, CDT

DOUGLAS PEARMAIN has over 35 years in the construction and roofing business. He has a B.S. from the New Jersey Institute of Technology and an AAS in HVAC, as well as his CDT certification with CSI. Pearmain has 25+ years of experience working on projects worldwide in tying together many expansion joint closures, roof perimeter, and building envelope systems. He assisted on ANSI/SPRI ES-1 and GD-1 standards and wrote and presented "Expansion Joints" for the Roofing Industry Educational Institute (RIEI) as a member of its accessories program. Pearmain was a faculty member of Better Understanding of Roofing Systems Institute (BURSI), the Building Products University (BPU) and has presented programs internationally. He has published three articles and has four patents for expansion joints.

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DAVID DIXON brings 17 years of commercial roofing experience from the manufacturers' side of the building envelope business. As a product representative, he has worked with technical and warranty services departments. He has served as a regional and district sales manager for the past six years. Dixon has presented programs at national and regional conventions, conferences, and other educational events. He has been actively involved with RCI, Inc. on several levels, as a past president of the Ohio Valley Chapter, RCI task force teams, and as a liaison with CSI. Dixon is both a Registered Roof Consultant and a Registered Roof Observer. Dixon is also very active with CSI, serving as a board member and Great Lakes Region president. He serves on the Indianapolis Chapter Education and Programs Committees and is a Certified Construction Contract Administrator, Certified Construction Product Representative, and a Construction Document Technologist.

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INTRODUCTION

Expansion joints (EJ) in a building envelope allow systems within a given constructed area to move independently of adjacent materials. Without proper expansion joints, buildings will ultimately determine where there should be relief and create a joint, resulting in mild component failure (*Photos 1* and *2*) to major failure of structural elements. Joints act to relieve stress and permit the building to move as necessary.

EJ closure systems are installed to span and seal the joints and protect the building interior from the outside elements. Fire-rated closure systems can be used to prevent the spread of fire where required by code. Exterior joints and interior joints can be integrated to "close" building systems for life-safety requirements or to improve energy management.

EJ closure product shapes, ratings, and mounting configurations all play into the proper selection of a product for a specific job condition. Finding the correct combination overall may prove to be elusive.

Proper closure systems will accommodate required movement and allow adjacent substrates to move independently without causing damage and to function as intended.

This paper will cover the following:

- General design considerations
- Movements
- Primary/secondary closures
- Insulated closures
- Fire-rated closures
- Integrating multiple expansion joint closure systems within the joints
- Transitions at various conditions
- Detailing differences: 2D, isometric, 3D, and Building Information Modeling (BIM).
- Specifications' critical role (synergistic with details)

Photo 1 – Patched significant roof split along the plies in a built-up system.

Photo 2 – Small, multipatch, split at reentrant corner of EJ with failure to carry through.

It is the hope that this information will assist organizations in their work and encourage greater participation by others in determining the best balance to the joint and closure solutions of the job. Should situations develop that warrant greater clarification at any stage, hopefully all aspects that change will be properly and universally communicated in a timely manner to avoid the perpetuation of incorrect information.

Overall, the industry is better prepared and equipped than ever to design buildings that can withstand almost anything anywhere. The details are what often prove to be the biggest challenges.

GENERAL DESIGN CONDITIONS

During the conceptual design of a building, it is never too soon to start thinking about the roll, location, and details of EJ closures. They traverse many conditions and continually challenge and interfere with something in the professional's vision of the finished structure.

Expansion joint voids result from all of the rest of the work that goes into designing a functioning building and its envelope. This is where the real challenge begins for all involved in the building. From the very beginning, accepting that the building may need expansion joints is a wise approach. The opening an EJ creates in the structure is the place where building envelope materi-

Joint No. /Grid Location, Wall+ or Roof+	Nominal/Designed Joint Size (UoM) @ Mean Temp*	Open** (UoM)	Close** (UoM)	Shear** +/- (UoM)	Vertical** (UoM)	Filler: Fire B., Insul VBG	Other: Type of Closure or Info
A/E5/W	150	50	50	X	-35	INS	Metal
B/C4/W	100	25	25	50	-45	FB	Roof mem EPDM
1/C4-10/R	125	75	75	25	X	FBG	Mfg bellows
2/G6-9/R	100	50	50	35	X	FB	Mix multi way

INS = insulated; FB = fire barrier; FBG = fire barrier gutter; UoM = unit of measure
+ Indicates a vertical or horizontal/slope application.
* Indicates the joint size/condition at a given temperature (varies by location and building use).
** Indicates the maximum designed or anticipated movements governed by applicable code requirements, including all factors.

Table 1 – Schedule of expansion joints and closure systems components.

als terminate. We will focus on the termination and resulting joint closure systems and installation.

One tool to assist with the expansion joints is to adopt a schedule format in one location for all parties to refer to because so many trades and materials can be influenced by the joint openings and closures. Constructing such a table and addressing the closure systems' needs will result in more accurate EJ openings to accommodate closure systems. An example is given in *Table 1*.

When verifying a joint condition or size, consider that warmer than normal/nominal conditions will make the joint smaller; colder conditions will make the joint larger. This does not mean that a larger or smaller closure system is needed. Confirm built joint size as close to a structure's normalized condition as possible. If a joint is constructed incorrectly, too small, or too large, a different-sized closure system may be required than that specified (*Photo 3*). The alternative is to correct the as-built situation to the design, if possible. Both of these methods will be covered in more detail later in the section on product selection.

Temperature changes over the year may represent the entire value in some areas of the world, while other areas may include seismic, severe weather, or periodic loadings from other sources and only make large movements under the worst conditions.

EJ closure systems for the building envelope will come in contact with many materials and conditions as they go over and around the features of the building envelope. It is very important to consider each change of materials and how they relate to one another. Should something protrude or recess from the nominal building face, verify that if it abuts an EJ, there is the continuity of substrate to which the closure system may attach and seal. Every change made in materials has the potential to affect surrounding materials for better or worse.

Closure systems for expansion joints in a building envelope need to be concerned with a host of conditions and materials that can be encountered in a single installation:

- Walls
- Roofs
- Soffits
- Interior and exterior conditions with possible joining
- Weather
- Ice and snow drifts
- Environmental
- Mixed EJ closure systems
- Orientation shifts
- Fire ratings
- Aesthetics
- Seismic
- Substrates
- Life and safety
- Sustainability
- Below-grade (specialized systems that will not be covered)

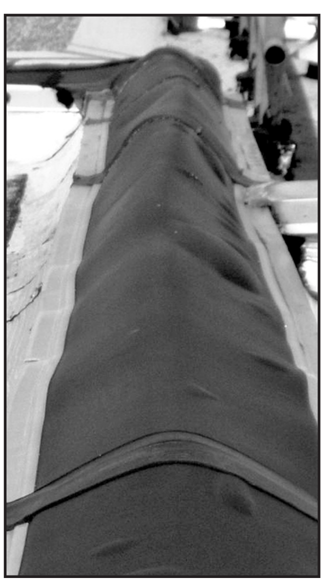


Photo 3 – Bellows rise some because curbs get a little closer as they go away. Some may be okay, but too much may require a different size.

Due to the variety of things that are on a roof, horizontal installations typically need to anticipate and make provision for many more conditions than encountered in a wall application.

When transitioning to a horizontal or sloped run on a roof, the following must be taken into account at some point (as well as the clearances for mounting configuration heights):

- Compatibility of joint and product orientations
- Alignment of wall and roof joints (avoid offsets if possible)
- Overall heights (curbs, height of roof flashings, mountings, counter flashings)
- Curbs/cants/crickets: minimum and maximum heights
- Parapet heights/intersecting walls
- Vent/HVAC penetrations
- Door sills
- Weep holes
- Sill flashings
- Soffits/cornices
- Copings, fascia, gutters
- Conduits/piping, lighting
- Scuppers or sumps (avoid cross-joint drainage if possible)

MOVEMENTS

In addition to all these criteria, EJs have the dynamics of the opposing structures to deal with, as well as weather resistance. These can range from small, simple straight-line thermal motions where failure may not be likely or critical to a combination of triaxial, large motions in highly critical functions involving all the conditions previously mentioned.

Movements are relative, but generally, depending on what building surface/view is being referenced, can be described as in *Figure 1*. They are 1) in/out or open/closed, 2) up/down, 3) back/forth or shear, or 4) rotational (combination of forces).

These movements, combined with mounting conditions or requirements, can make it necessary to increase the product by one or more sizes, which in turn will change mounting and/or clearances required for the assembly. It can become a Catch 22 in that one cannot always keep the same designed mounting or shrink a

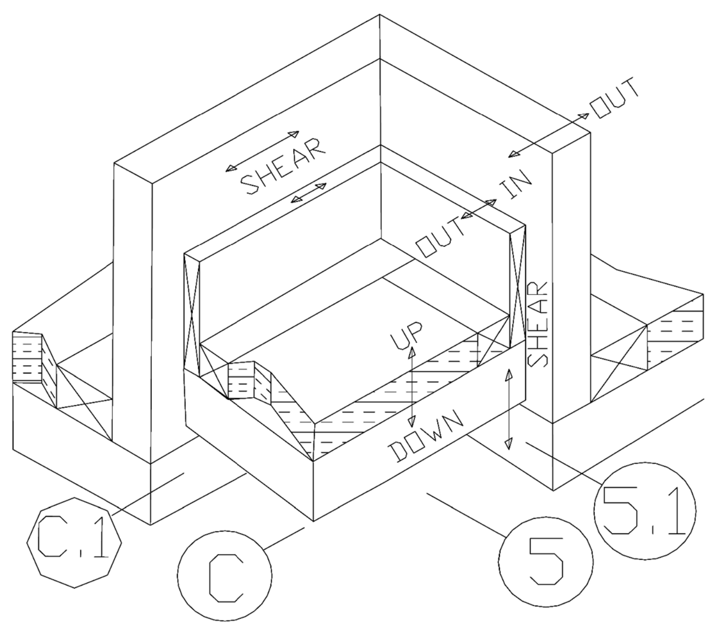


Figure 1 – Movements of joints in three dimensions and joint planes.

cover plate and still have it work.

A single closure system configuration that would do everything that the joint and building needed would be ideal. Unfortunately, nothing in this world fits every condition. Consequently, there is typically the need for more than one EJ closure system on a building envelope.

One concept that needs to be applied to all joint and closure systems is that of continuity. They do not stop and start randomly or just because something is in the way or may not have the desirable look (*Photo 4*). Think of them as plumbing or air systems that have to do all kinds of twists and turns to deliver their product. The joint and closure may need to transition in various ways:

- Change from roof to roof and roof to wall and maybe back again
- Go around an object on one or both sides
- Go up a parapet (*Photo 4*)
- Go over a roof edge (*Photo 5*)
- Jog to align (*Photo 5*)
- Go lower under a window

Typically, joints and closures only terminate at a foundation; however, there are rare exceptions. It is better to approach any change in a joint system as a point at which there must be a transition to another direction or product orientation, but not as an end. Product configuration changes are best done in the vertical with laps.

Photo 4 – Closures never meet and flashing is not split.

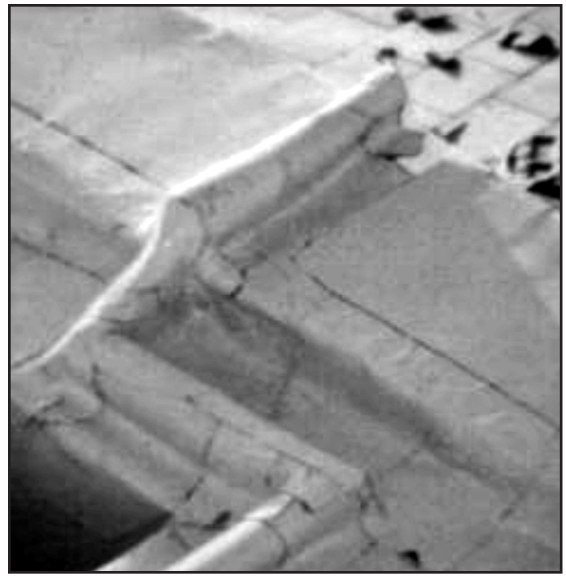


Photo 5 – PVC tube detail goes around gutter, then over parapet.

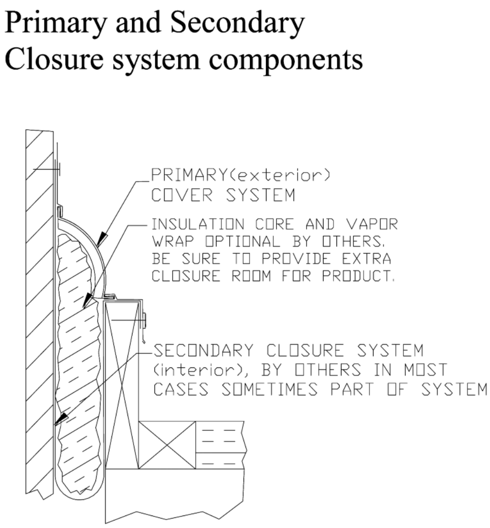


Figure 2 – Primary and secondary closure system components.

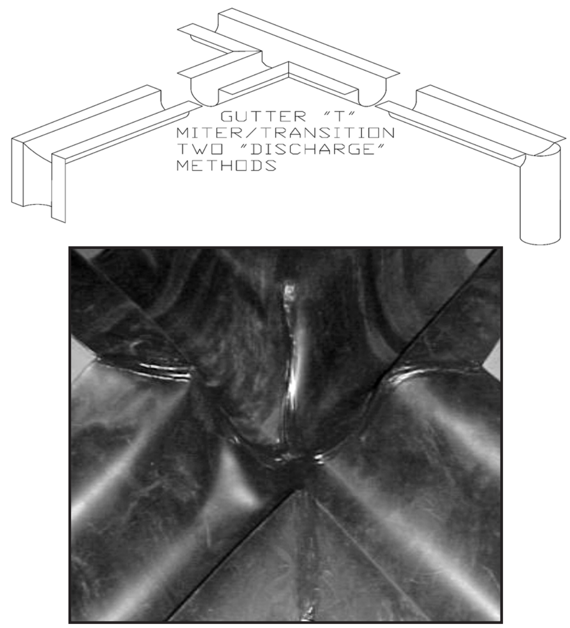


Figure 3 and Photo 6 – Factory premade "X" (photo courtesy of Johns Manville).

PRIMARY AND SECONDARY CLOSURES

EJ closures are subjected to all of the conditions to which all the rest of the building envelope components are, with the addition of movements in multiple directions. These systems are all primary in resisting the elements. Some are furnished with a secondary closure system (see *Figures 2* and *4*) that provides a backup, should the primary fail.

The integrity of the secondary closure system for roof systems becomes critical in that it is, by nature,

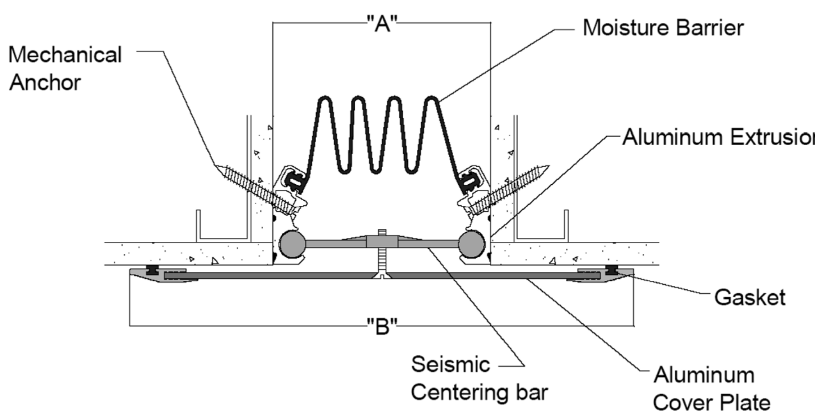


Figure 4 – Wall system showing primary cover and secondary bellows as a unit that works together (courtesy of Watson Bowman Acme).

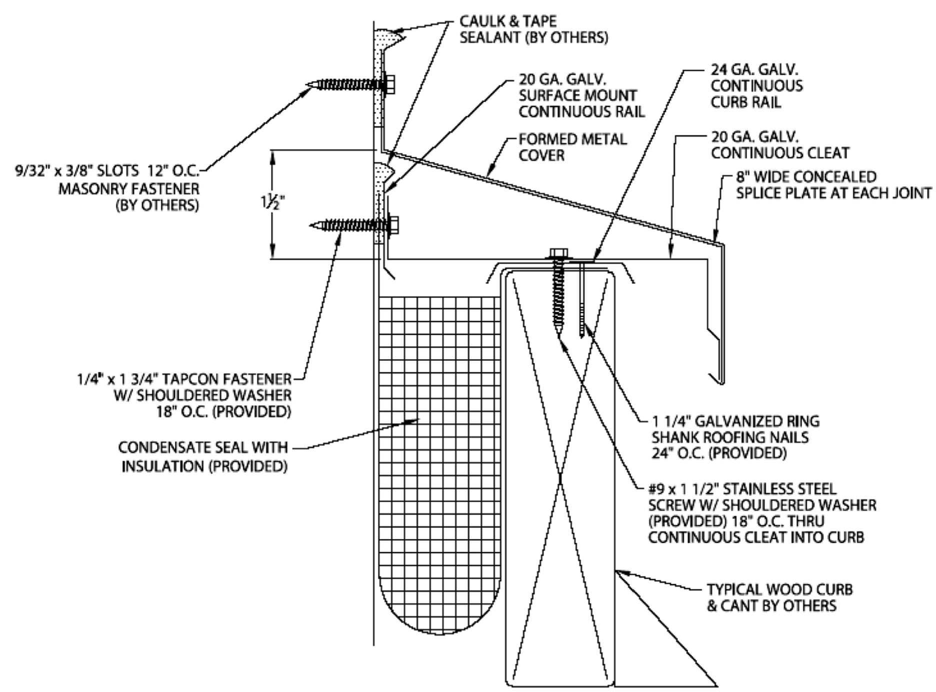


Figure 5 – (Courtesy of Metal-Era.)

a gutter configuration. Splicing and laps must be correct (*Photo 6* within *Figure 3*). As with any gutter, provisions are required for discharging moisture to appropriate places. This can mean using a vertical expansion joint closure as a downspout (*Figure 5*) or a bulkhead-type fitting assembly that will connect to an approved discharge point. Some wall joint systems have integral back seals. Any joint system from above must lap over the parts appropriately. This means that a roof joint secondary closure may overlap the inner or outer protection.

Any material laps must go with the slope and not buck the flow of fluids in the secondary/drainage runs. Intersections, such as *Figure 3* "T," "X," or "L" shapes and vertical changes must be installed and sealed with the flow. Tabbing of laps should be done on the underside. Factory-made and sealed transitions, as crossovers in *Figure 6*, may have two or three legs lapped one way and the other one or two the other way, depending on flows.

Attention to details and workmanship in these areas is absolutely essential because any breach in the system will become a funnel for moisture to enter the building.

Systems need some slope for best drainage, or at the very least they need to be flat and avoid negative slopes resulting in low spots that will pond moisture (*Figure 3*).

The secondary horizontal systems need uninterrupted runs between any two discharge points, such as downspouts or other outflow provisions. Just like any good roof or gutter design, having a minimum of two drainage methods for any section is necessary in case one should become blocked.

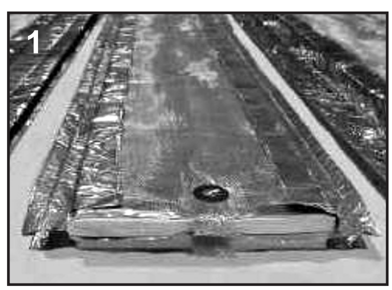
INSULATED CLOSURE SYSTEMS

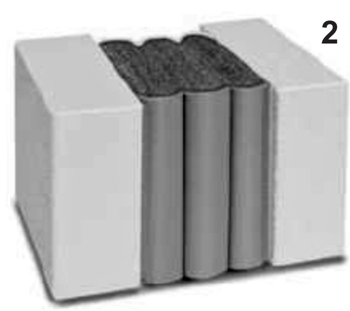
Today, buildings codes are changing and requirements regarding air barriers, better energy efficiency, LEED® compliance, and more changes are on the way. While the criteria for insulated expansion joints are not well established, the practice of filling a joint with insulation has been included in details for decades (*Figures 2* and *5*).

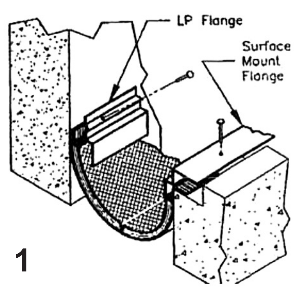
Some buildings need the expansion joints to have the same or as close as possible "R" values as the rest of the building envelope. The result can be more sophisticated specifications and elaborate assemblies. These may include a prescribed amount of insulation density wrapped in plastic tubes for insertion in a tube assembly. It could also mean prefabricated "log" EJ sections that nest sequentially in a joint as a system.

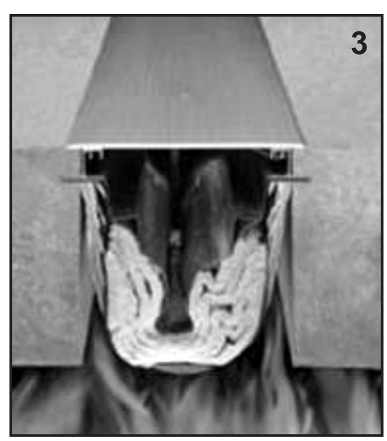
The depth of an insulated EJ core is important. It needs enough depth to effectively block off thermal shorts. Too short can be a waste of money and too deep may interfere with other elements. There can also be preinstalled gutter or fire barrier below the "logs." In some cases, the job can use an inner and outer closure system with encapsulated insulation installed in the space between the two closures. Cold storage or colder or hotter climates are areas in which these may be more likely to be used.

Depending on the specification and the expected movements, the joint opening may need to be enlarged. The insulation filling may take a limited amount of compression or cycles and therefore need a larger joint in order to have a smaller percentage of compression. This may necessitate a larger product and a different (higher or wider) mounting configuration. Addressing this early on in a project is advisable.









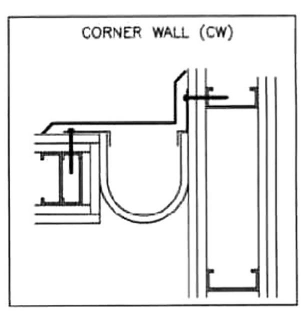


Figure 6 – Details and photos courtesy of 1) Thermal Structures, 2) Emseal, and 3) C/S Group.

FIRE-RATED CLOSURE SYSTEMS

The critical nature and purpose of fire-rated closure systems leaves no room for field or design interpretation of the tested and listed assembly configuration.

Fire-rated systems cannot be mixed and matched with any other brand, type, style, or configuration (*Figure 6*). Testing procedures and methods are very specific for an individual product setup that will include substrate, caulks, adhesives, splices, fasteners, anchor bars or flanges, fillers, and other accessories as applicable. Mixing, matching, and making substitutions with other materials or products is not an option.

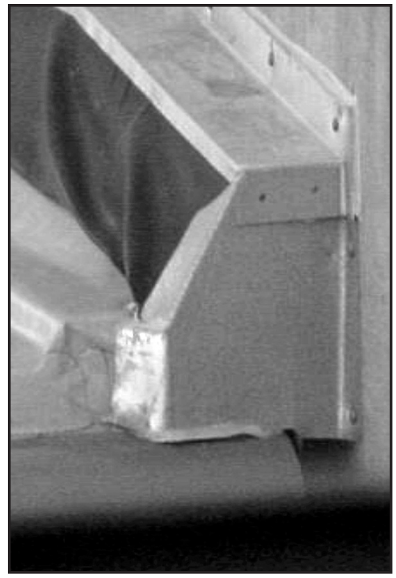
Installation of these systems must only be in accordance with their respective tested and listed configurations with specific accessories to specific substrates. This means that whatever make and model are used in a joint must be used in that whole connected joint system. If there is more than one joint system in the structure, then a different fire-rated system can be used so long as the two systems do not need to intersect.

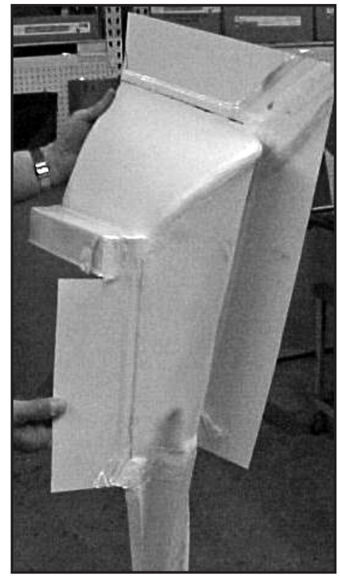
Fire-rated closure systems are a supplemental component to another expansion joint closure system that is the aesthetic, load-bearing, weather-resistant, or other appropriate functional system as acceptable by agency listing, be it interior or envelope oriented. They come in a variety of configurations, just like exterior closure systems, to achieve their purpose. *Figure 6* shows some of the configurations available.

Product sizes can change within a system with appropriately approved design accommodations. Splices of fire-rated system are a tested configuration component and must be assembled according to the prescribed methods. Miters/intersections must meet manufacturers' requirements; and, in some cases, factory-made miters are available and may be required.

Consult product tables very carefully to assure that the movements of the joint system will not exceed the closure's specifications. The manufacturers have already taken into account the maximum closure that will still leave room for the materials to function properly. This information must be adhered to. Know that it may conflict with and should supersede what other primary closure system might say movement could be. Be cognizant that the primary closure system may need adjustment as well. This is a situation in which communication and planning are critical.

Coordination, communication, and installation sequencing of fire barrier systems with other joint components and substrates are critical. There may be a need to stage the joint components and do partial installation and then wait on another trade to do something prior to proceeding.





Photos 7 and 8 – These two photos show the same basic condition. Both use bellows for the flexible closure. Photo 7 is capped with a metal "end" that has been caulked several times because of the shearing action at the rail and end cap interaction. It has failed to tie into or shingle over the lower system. Photo 8 (courtesy of Johns Manville) is a transition that makes the change to the vertical and then to another wall system with a mechanical tie-in that then will join the rest of the wall system.

SYSTEMS INTEGRATION: TYING IT ALL TOGETHER

When layering of the different products and materials at the building envelope level occurs, there are considerations that challenge the selection, design, detailing, and installation of the EJ closures. Sequencing of the primary, possible secondary, insulated, and fire-rated components for the outside seal and making them all fit and function through the wall assembly are not to be taken lightly. Complications can arise with the possibility of backing up to an interior EJ closure system.

The presence of a fire barrier is most important, and other components need to be worked with and around it while adhering to all the listing data. Many of these factors have been covered but bear repeating because they continuously get lost in the shuffle of multiple trades in a single area:

- Coordination
- Sequencing
- Miters
- Trades
- Clearances (possible larger openings for fillings and movements)
- Code-compliant substrates
- Specifications
- Drainage
- Compatibilities
- Tie-ins with interior joints

The installation of these systems can be very sensitive to the entire installed environment and related procedures. One of the first items to check is that the area to receive the closure system is, in fact, constructed per the listing data requirements. Depending on the type/style of product used, it may need to be installed from the top or the bottom or the front or back of the joint opening. In any case, the surrounding area must be clear and ready to receive the entire assembly, uninterrupted by anything. An error installing the components carries with it certain risks. All items deserve to be given respect. As we all know, water finds all kinds of ways to get into a structure. Water, vapor, smoke, and fire will all take the path of least resistance, and once they find that path, anything can happen.

The best route to follow is to have as few changes in products, materials, suppliers/manufactures, and trades as possible throughout the entire system. Deal with as few components as possible, as well. Purchase the most complete systems so as to avoid mix-and-match issues and inventing on the fly. The greater the initial detailing and information, the fewer missteps will happen.

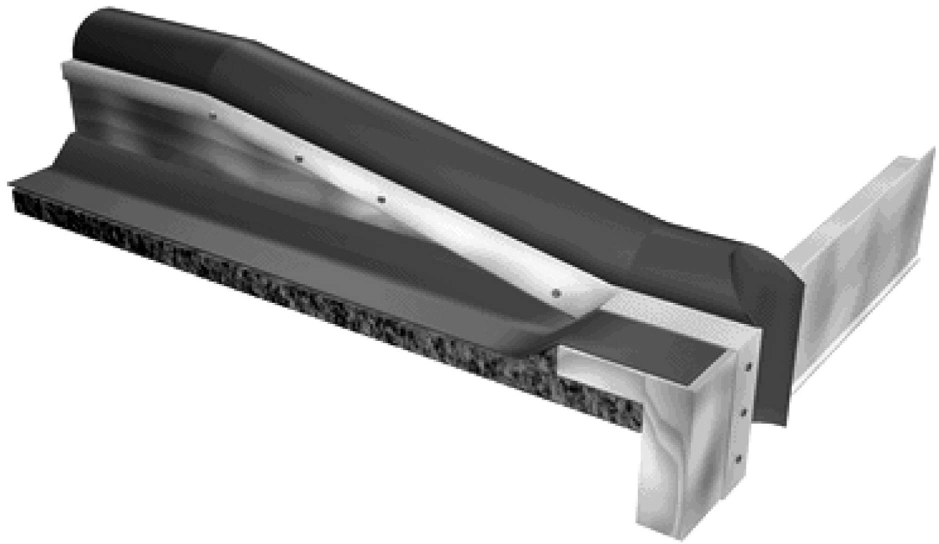


Figure 7 – Solid model that can be rotated for other views. BIM is similar but may also be parametric in that one can change elements by plugging into a formula/table. (Courtesy of Johns Manville.)

DETAILING

Due to the complexity of expansion joint installation, the information needed to do an appropriate job should consist of multiple views of the assemblies.

The common details are: plan(s), section(s), and elevation(s). These sometimes evolve into isometric or axiometric details, giving some perspective on how things go together from a collective viewpoint, but still in 2-D. Standard "flat" details, consisting of 2-D views, can provide answers to many basic questions. Yes, they are more work, but they give more information in one shot.

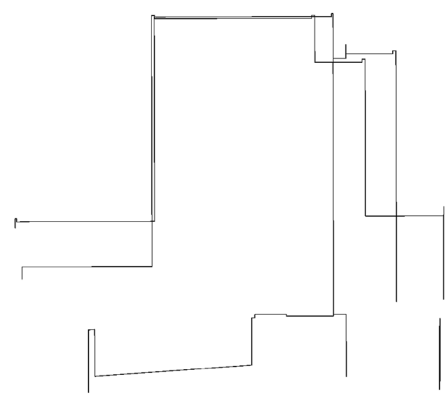
Isometric and axiometric details add the depth element to a detail; and if there is a need for more than one view, each one needs to be drawn from the new perspective. The drawing has no capacity to allow manipulation.

3-D drawings (*Figure 7*) construct a condition one time with x, y, and z coordinates and then take that composite item and move it around to see how it does or does not work in a given circumstance. These solid modeling and 3-D view systems will assist in engineering value up front and later on, will minimize valuable engineering time and effort. The 3-D drawing can also reveal sections from almost any angle, in case there is a question about the installation. These details/drawings can all be assembled into a complete building unit as a solid model.

BIM yields not only a 3-D assembly but also can carry lots of building product information: how many times a product is used, suppliers, contact information, and a host of other related material. In the event of a substitution, it is easy to find and replace an item and then get a new count, as well as address required changes.

In the absence of solid model or BIM capabilities, a mock-up can explain lots of problems and possible solutions all at the same time. Just like drawings, the more detailed a mock-up, the better the chances are of getting a condition correct.

Figure 8 shows an example of four views, three elevations, and the top of a traditional 2-D line drawing for expansion joints in a system of buildings and one 3-D (rotated) view. This comparison shows what can be understood in one drawing versus four.



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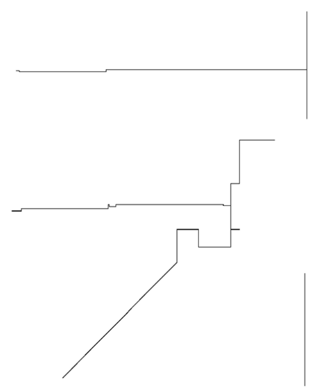

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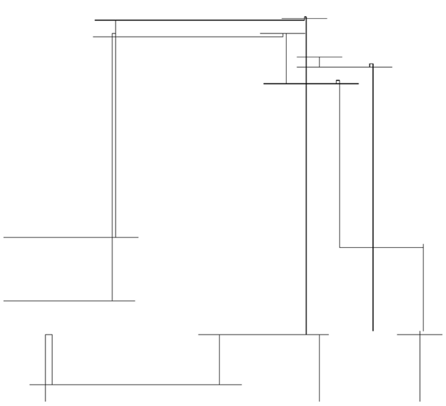

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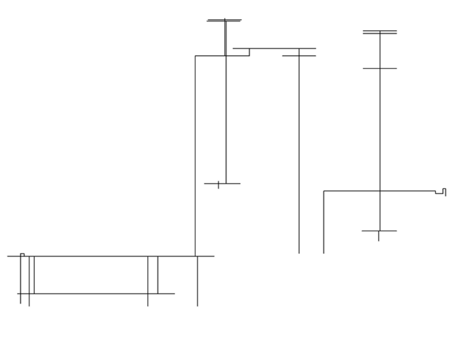

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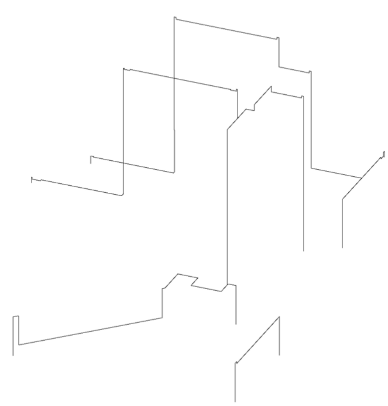

Left/Front/Above (ISO or true 3-D)

Figure 8

There are over 60 miter conditions in which one must address material interactions, sooner or later!

SPECIFICATIONS

Specifications for EJ closure systems need to follow the designs used in the building constructions details. This seldom means that they have to be proprietary, because almost every configuration and design has several variations and manufacturers from which to choose. The key is to keep each type and style specific to a joint's specific need. This is best accomplished with a table (see *Table 1*) giving the parameters of each joint or joint segment in case something must change along the way.

Expansion joints and closure systems take lots of work to ensure that they will perform not only graphically but also mathematically over the range of motion needed for all components. Failure to produce a specification that reflects the correct products accurately has the potential of starting the process over.

Specifications can create a very good guide for all trades involved with the joints. Expansion-joint closure specifications are longer than necessary and packed full of the entire "buffet" of information to cover them globally and rely on the details to be more of a guide. Unfortunately, this can create ambiguities and, potentially, a mountain of substitutions, RFIs, or change orders.

The job could be as straightforward as having all the joint conditions use the same configuration of materials. This then becomes a specification with a basis of one grouping of materials and a short list of other acceptable products carefully picked to have the needed characteristics. On the other hand, the schedule could become very long and involved, due to the number of conditions and joints. In this situation, it would be best to call out the assemblies by joint number with other acceptable systems.

This still leaves room for alternatives within a family of similar-style products. This procedure does not assure that they all work; there is the nagging issue of possible incompatibilities somewhere in the system. Any alternative product interfaces need to be confirmed as acceptable prior to acceptance. Acceptance without confirmation in most of these conditions could have unfavorable and costly results.

The more layers of an expansion-joint system there are, the more likely any change is to cause issues.

Warranties for the systems are also covered in specifications and may include multiple references, as roofing typically can provide an all-inclusive warranty for the accessories, too. Now that building owners and the design community are looking at the building envelope as an integral system, there may be occasions in which a more comprehensive building expansion joint closure system warranty will be called for.

The related sections of a specification for expansion-joint closure systems are something that, on even a simple job, can become a long list, depending on just how detailed it gets regarding the subsections. Consider all the material changes around the envelope.

CONCLUSIONS

Every job has risks and rewards based on balancing choices of cost and benefit. Expansion-joint closure systems are no different than any other item on a job, except that their dynamics are pivotal in the success of many other components working and surviving for the long term. Joint closures undergo more movement than most other building components. The amount and quality of the communication concerning understanding of these systems will play a key role in the system's success. Excellent resources and additional assistance are available from consultants specializing in the building envelope, manufacturers, and trade associations.

With a little more time in planning, detailing, and communicating on the front end, even before bidding or construction, there can be detail and specification improvements, resulting in a reduction of the challenges in the field and fewer RFIs and change orders. A second top priority should be to have a job conference with parties that are involved with any part of the job involving expansion joints prior to the start of construction and component ordering.

Expansion joints historically can make a big difference in the ultimate long-term results of the job. They do seem to take a disproportionate amount of time. Technology in many forms is assisting with details and specifications when the documents are being prepared. The amount of time and effort spent using today's technology and available information in advance can minimize extensive processing of Q-and-A's, planning, correcting, or repairing a compromised installation that may become a long-term issue. A successful installation can build long-term relationships concerning the building and beyond.