CHAPTER 3: ARCHITECTURAL FAÇADE STUDY

3.1 INTRODUCTION

This breadth topic is an architectural study of the rear façade of National Harbor Building M. In this chapter multiple façade system solutions will be examined and compared with the most beneficial system being chosen. Once a specific system is chosen it will be more completely explored and designed with specific architectural goals in mind.

In the original design of National Harbor Building M the rear façade was an 8" CMU masonry wall which encompassed four shear wall sections. These shear walls acted as the lateral resisting system in the longitudinal direction of the structure. In addition to providing lateral support, the CMU wall acted as a buffer between the office/retail building and an adjacent parking garage. Acting as a buffer the wall had virtually no openings, save the entrances to the two stairwells at each level located at each end of the building. While separating Building M from the parking garage, the wall provided some noise obstruction and acted as a fire wall.

The redesign of the lateral system as discussed in section 2.7 eliminated the need for the CMU wall to house the lateral system. This arose the question whether a CMU wall providing no structural support is the most efficient way to enclose the rear of the building. The façade system that would be used now would only need to act as a weather tight barrier which provides some noise obstruction and serves as a two-hour fire wall as specified by the architect. In addition to obtaining those goals efficiently, the façade system employed should be economically feasible and require fairly simple construction. With this in mind, several solutions were preliminarily explored and the top systems were compared.

3.2 COMPARISON OF POTENTIAL FAÇADE SYSTEMS

The façade systems which were selected from preliminary analysis to be further compared were a poured concrete wall, a CMU masonry wall, which was a modification of the original design, and a precast panel wall system. The advantages and disadvantages of each system were weighed and compared with the most all around system being selected.

Poured or cast-in-place concrete walls seemed like a logical choice to enclose the rear façade seeing that the rest of the building is being constructed of cast-in-place concrete. This type of façade would assure a water-tight barrier with it being formed against the structure as opposed to a separate system that requires additional sealing to become water-tight. The density and material properties of concrete would provide ample noise obstruction from the adjacent parking structure. Additionally, a cast-in-place concrete wall system can provide the required two-hour fire rating with only four inches of thickness (See figure 3-1). A four inch thick wall would have a unit weight of roughly 50 psf of wall area for normal weight concrete and 38.3 psf for lightweight concrete. The poured concrete wall system's main downfall comes in the area of economics and speed of construction. To construct a cast-in-place concrete wall formwork will be required. The additional cost and time associated with the formwork process make it a process which should be avoided if possible.

FIRE RESISTANCE RATINGS/MINIMUM REQUIRED EQUIVALENT INCHES

Aggregate Type in Concrete	Fire Resistance						
	0.5 Hr.	0.75 Hr.	1 Hr.	1.5 Hr.	2 Hr.	3 Hr.	4 Hr.
Calcareous or siliceous gravel	2.0 in.	2.4 in.	2.8 in.	3.6 in.	4.2 in.	5.3 in.	6.2 in.
Limestone, cinders or slag	1.9 in.	2.3 in.	2.7 in.	3.4 in.	4.0 in.	5.0 in.	5.9 in.
Expanded clay, shale or slate	1.8 in.	2.2 in.	2.6 in.	3.3 in.	3.6 in.	4.4 in.	5.1 in.
Expanded slag or pumice	1.5 in.	1.9 in.	2.1 in.	2.7 in.	3.2 in.	4.0 in.	4.7 in.

Fig. 3-1

A CMU masonry wall system can be constructed rather easily and at an efficient pace. Although it will be constructed on site, no additional formwork will be required. Since the wall will only be carrying its self weight and not lateral loads, much less reinforcement and grouting would be required when compared to the original design. This reduction in the grouted percentage of the CMU units will decrease the wall's acoustical and fire resistive properties. However, as confirmed by figure 3-2, an 8", partially grouted CMU wall will still produce adequate fire resistance to meet the required two-hour rating. The density of the CMU block, regardless of the amount of grouted cells, should still provide an acceptable level of noise obstruction from the parking garage. One drawback of implementing this system would be that it is not consistent with the construction material making up the rest of the structure. The construction would require an additional group of trades people on site and thus more coordination.

FIRE RATINGS OF CONCRETE MASONRY WALLS
EXPANDED CLAY, SHALE OR SLATE AGGREGATES

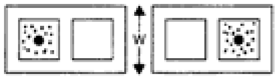
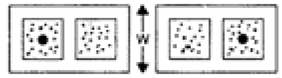
Width (W)		Fire Resistance Ratings	
			
Nominal	**Specified**	**Partial Grouted or Hollow Masonry**	**Solid Grouted Masonry**
4"	3 5/8"	Less than 1 Hour	2 Hours
6"	5 5/8"	1 Hour	4 Hours
8"	7 5/8"	2 Hour	4 Hours
10"	9 5/8"	2 Hour	4 Hours
12"	11 5/8"	3 Hour	4 Hours

Fig. 3-2

A precast wall system is similar to the poured concrete wall system in its material properties and therefore achieves the same fire rating and acoustical goals. Where it differs from the poured system is that it is prefabricated off site. This feature will allow the wall to be constructed without on-site formwork and curing saving time and additional labor. The flexibility of precast design could also lead to cost saving if a precast system were utilized. Since this rear façade will only be facing an exterior wall of a parking structure, it will not be a visible façade. This could lead to savings if the design does not have to adjust the precast mix for color or specific aggregate mixtures, both are details which can drive up precast costs. Using the precast concrete will also stay true to the material of the rest of the concrete building.

After examining the three façade systems, it appears that the precast wall system offers all of the benefits of the other systems without some of the draw backs. It is very similar to the poured concrete wall system but has the advantage of being prefabricated and shipped onto the site for erection only, thus eliminating the use of formwork. Also in general the precast concrete seems to make more sense with a concrete building than CMU wall would. The advantages of precast walls are also highlighted in a table found in an article comparing different wall systems, see figure 3-3. While it compares other systems not discussed here, it has a good comparison with the CMU system in some more general areas.

	PRECAST WALL SYSTEMS	MASONRY	METAL PANEL	TILT-UP
Design Flexibility	X	X		
Factory Controlled Production to Assure Quality	X		X	
Thermal Efficiency	X			
Water Leak Resistance	X			
Low Maintenance	X			X
Durability	X	X		X
Low Life Cycle Costs	X			
Year Round Fast Construction	X			

Fig. 3-3

3.3 SELECTION OF A PRECAST SYSTEM

The flexibility of design of precast façade systems offers a number of options that can be considered to customize the application. For the rear façade of National Harbor Building M precast panels used as cladding or curtain walls will be examined. A cladding or curtain wall system typically uses one of three standard wall systems (See figure 3-4): conventional wall system, sandwich wall system, or rain screen wall system. The sandwich wall includes two layers of precast which enclose insulation. This system increases the façades thermal properties; however since it would be applied to only one wall of the building, it would produce minimal results. The rain screen wall system is also comprised of two layers of precast panels, a feature that is not needed for this application. Of the three typical wall systems the conventional wall achieves the required goals most efficiently.

The precast façade system implemented will be a wall-supporting unit, or a system which supports only the wall itself and does not carry any loads from the floor or roof slabs. The panels of this system can either bear on the structure or be stacked and bear on the panels below as illustrated in figure 3-5. In the stacked arrangement the precast façade carries all of its own self weight and is only attached to the structure for lateral stability. The advantage of a stacked system is that it eliminates additional gravity loading on the structural slab. The stacking of precast panels is limited to relatively short buildings because tall walls would require the lower precast panels to carry excessive weight. With Building M being only 5 stories and 74 feet tall it is an ideal application for a stacked wall supporting precast unit.

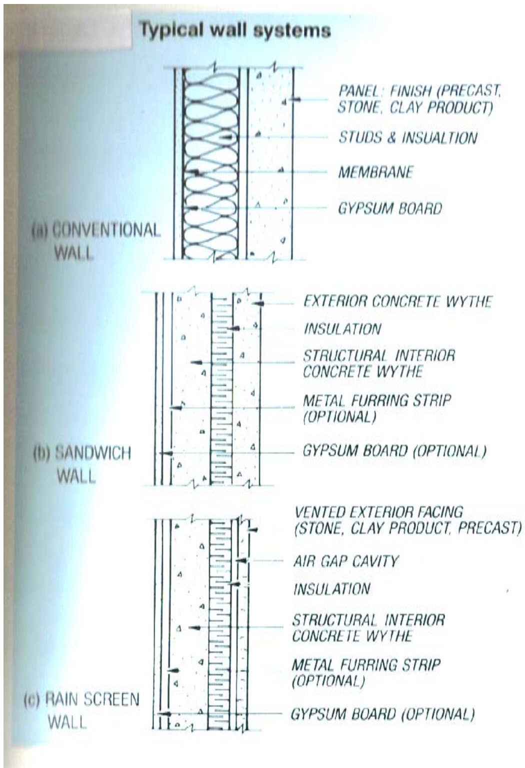


Fig. 3-4

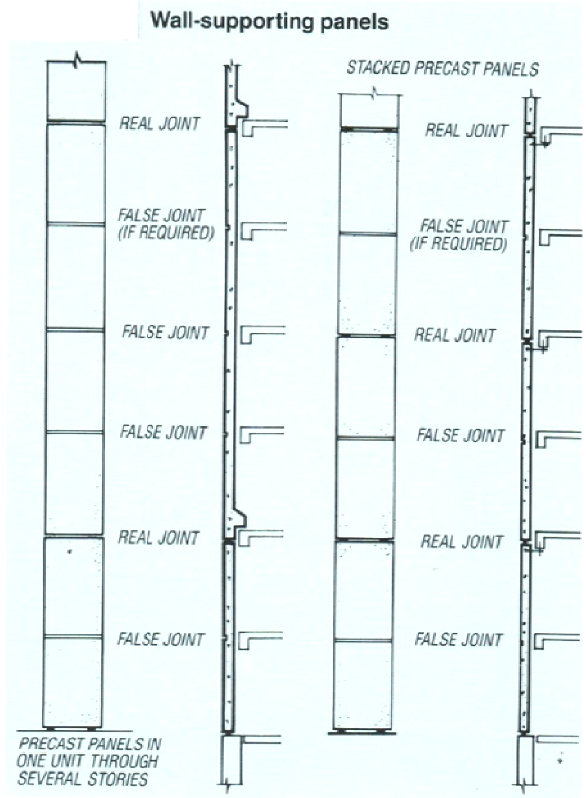


Fig. 3-5

The main function of the rear façade is to enclose the building, and thus will have limited openings. The layout of this precast system will contain mainly solid wall panels. When designing solid panels, major design and cost considerations included panel finish, shape, size and repetition. With this rear façade facing a parking structure separated by only four inches, panel finish is an area where economic savings can be accomplished. The cost of generating specific colors and aggregate mixtures can drive up the price of the precast panels. Using basic mixtures that are not enhanced with specific aggregate types and cement that is not modified to achieve certain colors will be acceptable for this application. The cost of aggregate can range from 5 - 20% and cement from 4 - 8% of the total cost. One cost saving example that could be implemented is the use of gray cement versus white cement. White cement which is used for color enhancement and uniformity is on average 2 – 2.5 times more expensive. When it comes to shape, the more regular the shape of the designed panel, the cheaper and easier to construct the panels become. The wall being constructed is rectangular in shape and contains no jut-outs so a rectangular panel will be selected. As for size, stacked units are typically designed either as slender multi-story panels or as wide single story panels that run approximately the length of one bay. For this application the wide single story panels make slightly more sense because they are more efficient at spanning openings. While there are not many openings in the rear façade, the slender panels would be more difficult to design around the stairwell entrances.

Repetition is probably the single most important factor to consider when designing precast walls. Well designed precast wall systems contain only a few main panel shapes which can be modified into other required panels. This allows the manufacturer to use significantly less forms when they are casting the panel which are referred to as Master Molds. The rear façade will consist of two basic forms which will be slightly modified at certain locations. The base level will be constructed of 30'-8 1/8" wide by 20' tall panels, while the upper stories will be constructed of 30'- 8 1/8" wide by 13.67' tall panels. At panels where there are openings for the stairwell entrances, blocking can be inserted into the master mold to obtain the desired form.

3.4 FIRE RESISTANCE

In the original design of National Harbor Building M the reinforced CMU wall, in addition to being a part of the lateral system, acted as a fire barrier. This wall separated the office/retail building from the adjacent parking structure with a two-hour fire rating. In order to be an effective replacement for that wall system, the precast wall system being designed must also obtain at least the required two-hour rating.

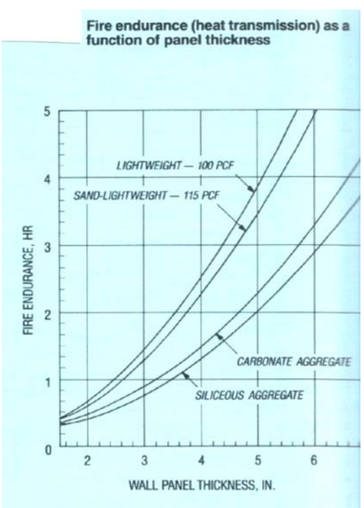


Fig. 3-6

Fire endurances for single-course concrete panels

Aggregate	Thickness in inches for fire endurance of			
	1 hr	2 hr	3 hr	4 hr
All lightweight	2.47	3.56	4.35	5.10
Sand-lightweight	2.63	3.76	4.62	5.37
Carbonate	3.25	4.67	5.75	6.63
Siliceous	3.48	5.00	6.15	7.05

Fig. 3-7

The fire rating for solid precast panels used in the conventional wall system is proportional to the panel's thickness. Therefore the thickness of the panels used in this design will be controlled by the required fire rating. With this wall system not contributing to the structural integrity of the overall building, it is acceptable to use a sand based lightweight concrete mixture. The chart presented in figure 3-6, values summarized in figure 3-7, gives the required thicknesses for precast panels based on their concrete mixture. For the sand-light weight concrete and a two-hour fire rating a minimum thickness of 3.76” is determined. This value is rounded up to obtain a panel thickness of four inches.

3.5 DETERMINATION OF LOADS

The precast wall system selected carries no loads from the structure, thus only must resist loads generated by its self-weight or other loads applied directly to the panels. These loads include the self-weight of the panels above bearing down, seismic loads generated by each individual panel’s self weight and wind loads.

The self-weight of one of the upper panels is approximately 15,700 pounds. The maximum bearing load would be above the panels at the base of the wall which have the weight of four panels bearing on top of it. At this location the maximum bearing load per panel is 4 x 15,700 pounds or 62,800 pounds.

The in and out direction of the panel corresponds to the transverse direction of the building. This direction is controlled by wind (See controlling loads discussion in section 2.7.2) and the worst case will occur at the top level where the wind pressure is greatest. The wind pressure acting on the top level of precast panels is 27.3 psf (See section 2.4). With the panels having an approximate square footage of 410 square feet, the service wind load on each panel is 11,193 pounds.

The seismic forces developed as a result of the panels self-weight will act in the long direction of the panels, the longitudinal axis of the building. These forces were calculated following a design example found in the PCI code and equal 4451 pounds. A summary of all the loads acting on a typical panel can be seen in figure 3-8, and more detailed calculations can be found in the appendix.

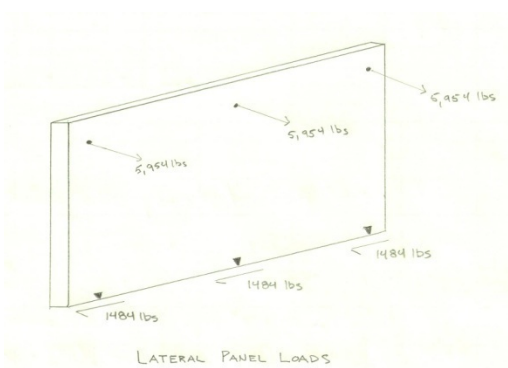


Fig. 3-8

3.6 CONNECTIONS

The connections of the precast wall system act as the means for the panels to transfer their loads to the supporting members. In the case of the gravity loads, the bearing connections are simply transferring the loads to the panels below and eventually into the foundation. As for the lateral forces, the connections are used to brace the panels to the concrete building structure providing support. The connections used for the wall system are typical connections selected from the Architectural Precast Concrete manual. Once selected, the connections would be checked against the factored loads solved for in the previous section.

A direct bearing style connection was selected to transfer the gravity loads from panel to panel (see figure 3-9). While the specific connection selected requires more detailing than the basic shim stack style connections in the manual, its benefit is that it provides some lateral restraint. With Building M being located in a low seismic region, SDC B, the PCI code does not require additional lateral bracing if there is lateral restraint provided in the bearing connection. Had the shim stack connection been selected because it was easier to construct and required less detailing, an additional lateral connection would have needed to be added. The addition of another connection would have neglected the advantages gained from selecting the simpler connection.

With the direct bearing connection handling the gravity and seismic loads, the remaining wind loads can be transferred through a lateral tie back. The force resisted by this connection will be: 1.6(11,193 lbs) / # of connections per panel. The connection selected is a welded tie-back that relies on a bracing angle to direct the load into the underside of the slab (See figure 3-10). This connection is best used in conjunction with a direct bearing connection like one implemented in this system. The bearing connection will take all of the gravity loads and prevent the bracing angle of the tie-back from acting as an axial member. At areas where the precast panels are applied over a shear wall, a different welded tie-back shown in figure 3-11 will be used. This connection provides similar support and is able to be applied at areas where access to the underside of the slab is not available.

Connections should be placed only where necessary and should avoid redundant supports so the panel can move and deflect freely. Typically that means only two bearing and two lateral supports on each panel, with the supports being placed at the corners. However, the length of the panels used on this façade may lead to bowing if they are unsupported for their 30 foot span. To prevent bowing three sets of connections will be used along each panel. The panel and connection layout can be seen in figure 3-12.

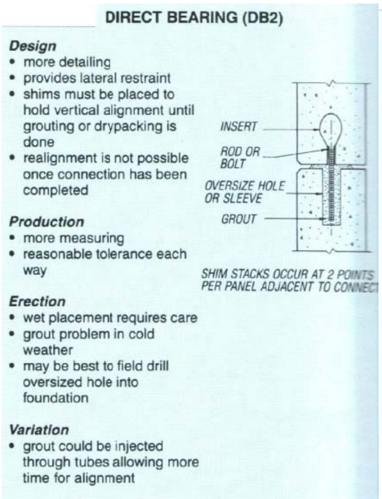


Fig. 3-9

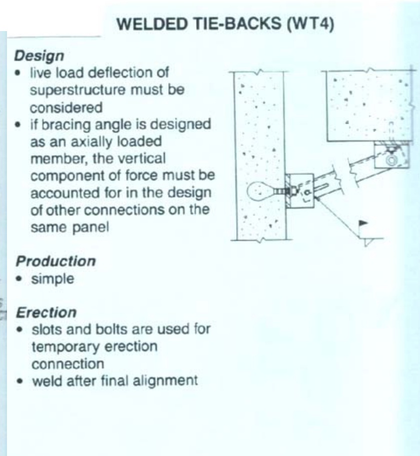


Fig. 3-10

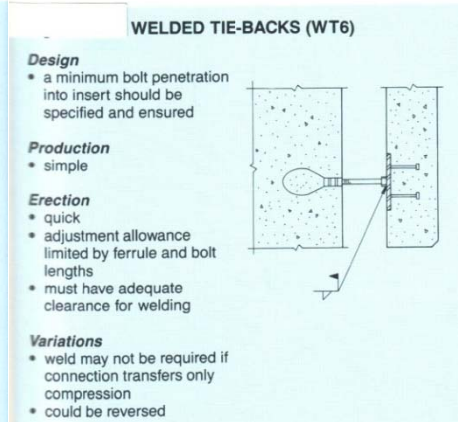


Fig. 3-11

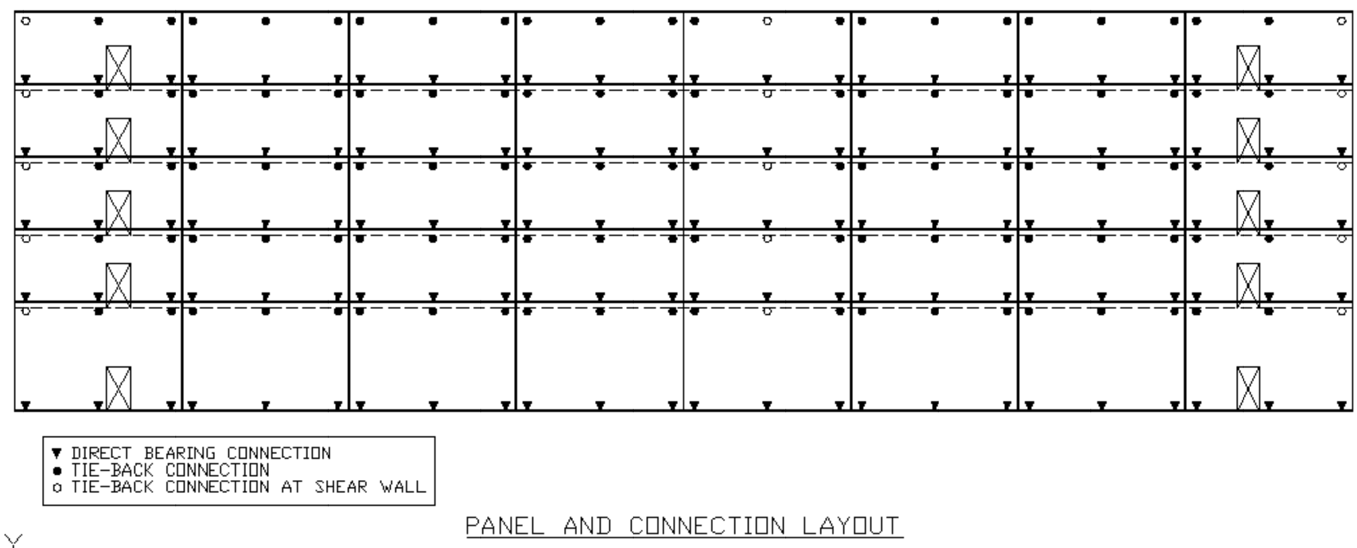


Fig. 3-12

3.7 JOINTS AND SEALANTS

Joints and the sealants which fill them are considered the weakest link in the overall water-tightness of a façade system. This makes the design of joints a critical task in the process of a façade study. When designing joints, it is recommended to design first for weather protection, then for panel movement, and finally for appearance.

3.7.1 Type of Joints

The type of joint that is selected can go a long way towards preventing water penetration. For this façade a recessed butt joint will be used as opposed to a basic flush joint. The recess is desirable over the flush application because it helps to shield the joint from constant exposure to the weather, particular in the horizontal joints. Figure 3-13 shows a profile of the selected horizontal and vertical joints.

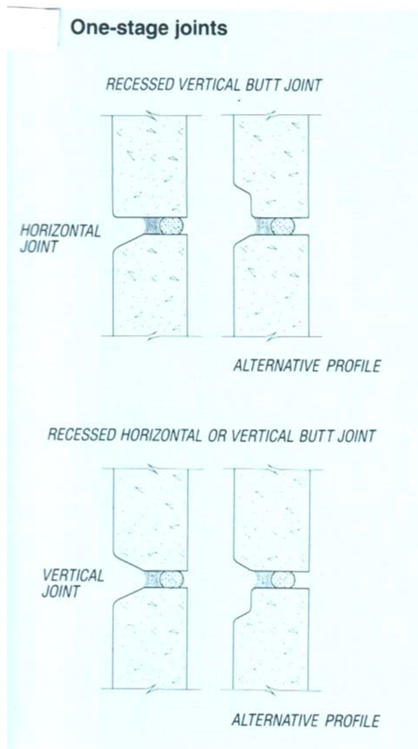


Fig. 3-13

3.7.2 Size of Joints

The width of joints is determined based on the expansion and contractive thermal properties of the panel and the extensibility of the sealant used. The coefficient of thermal expansion for sand lightweight concrete can be taken as: 5x10^-6 in/in/deg. F. Using this value and assuming an extensibility of 25% for the sealant a 30' wide panel will require a 0.97" wide joint based on an equation given in the Architectural Precast Concrete Manual. For ease of construction, a 1" wide joint will be specified for horizontal and vertical joints. The required depth of the joint is proportional to the width and will need to be 1/2". The joints will be backed up by backer-rod which will be inserted into the joint allowing the sealant to be applied to the required depth.

3.7.3 Sealant Material

Joints are only as effective as the sealant which fills them, thus the selection of sealant material must be examined. A comparative chart of typical sealant materials is shown in figure 3-14. This chart was used to select the material most appropriate for the joint application of the rear façade. A two-component Polyurethanes based sealant was selected as the best option. Some of the characteristics of this sealant that were important were its extensibility which matched the assumption made while sizing the joints, its resistance to compression rating, its weather resistance and cut, tear, abrasion resistance. These properties show it is a very durable sealant material that will likely not require much maintenance. The only area the sealant does not rate well is its resistance to direct ultra violet rays which will not be a problem because the wall will not be in direct sun light being adjacent to the parking structure. Additionally, the maximum joint width of the material is two inches which is larger than the specified joint width of one inch.

Comparative Characteristics and Properties of Field-Molded Sealants

	Polysulfides		Polyurethanes		Silicones	
	One-Component	Two-Component	One-Component	Two-Component	One-Component	One-Component
Chief Ingredients	Polysulfide polymers, activators, pigments, inert fillers, curing agents, and nonvolatilizing plasticizers	Base: polysulfide polymers, activators, pigments, plasticizers, fillers, Activator: accelerators, extenders, activators	Polyurethane prepolymer, filler pigments & plasticizers	Base: polyurethane prepolymer, filler, pigments, plasticizers, Activator: accelerators, extenders, activators	Siloxane polymer pigments & fillers acetoxy system	Siloxane polymer pigments: alcohol or other non-acid cure
Primer Required	usually	usually	usually	usually	usually	occassionally
Curing Process	chemical reaction with moisture in air & oxidation	chemical reaction with curing agent	chemical reaction with moisture in air	chemical reaction with curing agent	chemical reaction with moisture in air	chemical reaction with moisture in air
Tack-Free Time (hrs.) (ASTM C679)	24	36-48	24-36	24-72	1	1-2
¹Cure Time (days)	7-14	7	7-14	3-5	7-14	7-14
Max. Cured Elongation	300%	600%	300%	500%	300%	400-1600%
Recommended Max. Joint Movement	±25%	±25%	±15%	±25%	±25%	±25% to +100, −50%
Max. Joint Width	¾″	1″	1¼″	2″	¾″	1″
Resiliency	high	high	high	high	high	moderate
Resistance to Compression	moderate	moderate	high	high	high	low
²Resistance to Extension	moderate	moderate	medium	medium	high	low
Service Temp. Range °F	−40 to +200°	−60 to +200°	−40 to +180°	−40 to +180°	−60 to +350°	−60 to +300°
Normal Application Temp. Range	+40 to +120°	+40 to +120°	+40 to +120°	+40 to +120°	−20 to +160°	+20 to +160°
Weather Resistance	good	good	very good	very good	excellent	excellent
Ultra-Violet Resistance, Direct	good	good	poor to good	poor to good	excellent	excellent
Cut, Tear, Abrasion Resistance	good	good	excellent	excellent	poor	poor-excellent
³Life Expectancy	20 years +	20 years +	20 years +	20 years +	20 years +	20 years +
Hardness Shore A (ASTM C661)	25 - 35	25 - 45	25 - 45	25 - 45	30 - 45	15 - 35
Applicable Specifications	FS:TT-S-00230C ASTM C920 19-GP-13A (Canadian)	FS:TT-S-00227E ASTM C920 19-GP-24 19-GP-3B (Canadian)	FS:TT-S-00230C ASTM C920 19-GP-13 (Canadian)	FS:TT-S-00227E ASTM C920 19-GP-24 (Canadian)	FS:TT-S-00230C FS-TT-S-001543A ASTM C920 19-GP-9B (Canadian)	FS:TT-S-00230C FS-TT-S-001543A ASTM C920 19-GP-18 (Canadian)

Fig. 3-14