Appendix B

Mechanical Breadth Calculations

EIFS References

resistant mesh in one instance, the spacing of both warp and weft was 4.25 mm in all samples. The mesh from two samples appeared to have no polymer coating. The remaining samples were coated with yellow, blue, white or clear polymer coatings.

In general the samples were reported as being of good quality, conforming to the EIMA Guideline Specifications [3], with a few exceptions.

Table 2--Individual test results

Bldg. No.	Lamina weight, kg/m²	Polymer content, %	Water absorption, %	Base coat(s), mm	Finish coat(s), mm	Mesh weight, kg/m²
1	3.1	10.2	7.2	0.5 - 0.75	0.1 - 2.0	0.12
4A	7.5	10.4	6.0	1.0 - 1.9	1.5 - 4.0	0.13
4C	4.5	10.6	8.2	1.0 - 1.2	0.2 - 2.5	0.14
5	4.0	10.9	8.9	0.5 - 2.0	0.5 - 2.0	0.13
10A	4.0	9.5	10.1	0.1 - 0.2 plus 1.2 - 1.5	0.2 - 1.0	0.13
10B	5.2	12.3	6.1	0.75 - 1.0 plus 0.75 - 1.0	0.5 - 0.75	0.13
11	6.9	12.4	2.7	2.0 - 2.25	1.0 - 1.5	0.11 x 2
12	5.7	14.0	5.7	1.1 - 1.3 plus 0.5 - 0.6 plus 0.1 - 0.3	0.1 - 1.5	0.11
15	6.0	12.6	7.9	2.5 - 3.2	0.1 - 1.5	0.14 plus 0.59
22	2.7	14.6	8.8	0.5 - 0.75	0.1 - 0.75	0.12

FIELD OBSERVATIONS

The finish was in excellent condition in many cases, including the oldest installation (13 years), on a high-rise cast-in-place concrete wall. More than half of the installations were in good to excellent overall condition, although none were entirely free of defect. Approximately 30% had visible problems serious enough to threaten serviceability. Ingress of moisture into the system and impact damage were the most common causes of damage serious enough to demand repair or replacement.

Problems observed included: failed joints, cracking, impact damage, excessively thin applications, softening, erosion of the finish, delamination of the finish coat, delamination from the insulation, poor attachment of insulation to the building, fading, freezing prior to cure during construction, color variation dating from installation, color variation due to fading, cracking at locations of movement in underlying supports, unsatisfactory repairs, algae and moss growth on the surface, water saturated insulation, damage from interior water sources, and complete detachment of the system from the building.

The common problems were cracks, particularly at reentrant corners, failed joints where sealant had been used, deterioration due to moisture, and damage due to impact. A subjective view of the frequency and severity of these problems is tabulated (Table 3). "..." indicates negligible occurrence. More severe problems are rated as "■", "■■", or "■■■", in ascending order of severity. The "■■■" designation is reserved for instances which threatened the overall appearance of the building, the serviceability of the cladding (unless promptly repaired), or where failure necessitating replacement had already occurred. Figures 1 to 7 give some indication of the damage observed. On Building 4C one third of the windows had one or more cracks 0.1 to 1.0 metres long extending across the building face from window opening corners. Similar, but more extensive, cracking was observed on Building 10, where cracks extended from one window to the next in several locations, from grade to parapet. See Figure 1. On Building 5, impact damage was evident on every elevation, with each typical 10 metres of building perimeter bearing 50 to 100 impacts ranging from fist-sized dents to patches of bare concrete like that shown in Figure 2. Figure 2 also shows more typical damage, adjacent to a garbage container on Building 1, from a falling object on an upper floor of Building 15, and by snow sliding from a roof on Building 4A. On Building 11 the lamina was cracked at many of the joints in the insulation. In addition, in some areas, it was cracked at every strand in the glass mesh. See Figure 3. The insulation was saturated with water in several locations. On Building 7, sealant in building expansion joints had failed for the full building height (as in Figure 3) and one failed sealant joint had caused interior water damage. Figure 3 also shows moisture damage to finish coat on Building 4A. On Building 21, moisture damage to gypsum sheathing had resulted in loss of a section of EIFS cladding 3 stories high and approximately 15 metres wide.

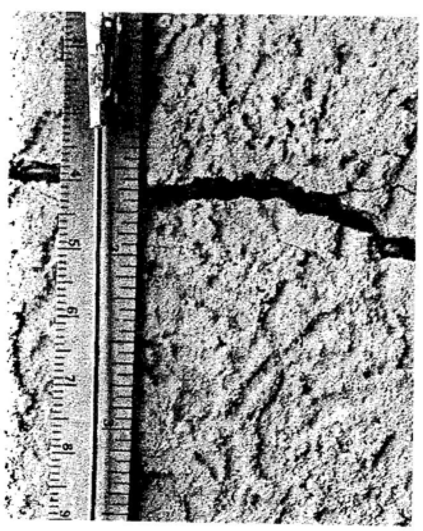

Fig. 1--*Window corner cracks: Building 4C at left, Building 10 at right. Joint-like feature on Building 10 is deliberately exposed white finish under contrasting top layer.*

Table 3--Observed problems

Building	Cracks	Joints	Moisture	Impact
1--High Rise Residential	■■	...	■	■
2--Recreation Centre	■	...	...	■■
3--Shopping Centre	■■	■■	■	■
4A--Hotel	■■	■	■■■	■
4B--Hotel	■	...	...	■
4C--Hotel	■■	■■■	...	■
5--Recreation Centre	■	■	■	■■■
6--High Rise Residential	■	■	...	■
7--Hotel	■	■■■	■	■
8--High Rise Residential	■■	■	■■■	■
9--Hotel	■■	■	■	■
10--Office	■■■	■■	■■	■
11--High Rise Residential	■■■	■■	■■■	■
12--High Rise Residential	■	■	■■	...
13--High Rise Residential	...	■	■	...
14--Hotel	■	...	...	■
15--Hotel	■	■■	■	■
16--Low Rise Residential	■■	■■	■	■
17--Restaurant	...	...	...	■
18--Low Rise Residential	■■	...	■	■
19--Retail/Residential	■■	■	■	■
20--Retail/Office	■	■	...	■
21--Shopping Centre	■■■	■	■■■	■
22--Retail/Office	■	■	■	■
23--Office	...	■	...	...

RECOMMENDATIONS

The following points summarize recommendations for application of EIFS to future projects, based on the failures observed:

- Mandate architectural technical input. Provide shop drawings indicating joint details, joint spacing and junctures. Have inspections completed by qualified and experienced third parties on all significant projects.
- Don't use EIFS in high impact areas or on stud framing with gypsum sheathing, if a physically secure wall is required. Use more impact resistant material such as concrete, or masonry, particularly at loading docks, parking spaces, and roadways.
- Use windows which can be cleaned from the interior, except where they are accessible from the ground or balconies without ladders or staging.
- Design the cladding, and all attachments, to withstand the full wind load.
- Use gypsum-based boards as substrata only when air sealed and waterproofed with a membrane on the outside. Otherwise, consider a more moisture resistant sheathing containing no gypsum; exterior and water resistant gypsum boards are not sufficient.
- Insulation in the stud spaces of frame walls supporting EIFS should be used only after thermal profiles have been considered for the winter design condition to ensure that the dew point will always fall in the EIFS insulation layer.
- Dark colors fade and deteriorate more rapidly, and subject the surface to more extreme temperatures, both in sunlight and on clear cold nights.
- Locate soft joints in line with corners of openings, to eliminate opportunities for cracking.
- Use two stage (rain screen) joints, like the typical drained joint described by Schaefer & McKechnie.[5] Use something other than sealant for the outer seal, where possible. Don't install finish coat on sides of joints where sealant adhesion is required.
- If sealant is used, use low modulus sealant with controlled minimum cross sections. Use a brand of sealant known to be compatible with the particular brand of EIFS. Take greater care than for sealant installations in other materials.
- Use metal expansion joints attached to the underlying structures to avoid bridging gaps between structurally independent EIFS-clad building segments with sealant, and terminate the EIFS at junctures where no movement will occur.
- Provide mounting for signs and other fixtures, independent of the EIFS.
- Secure EIFS to rigid substrata such as concrete or masonry where possible. If flexible supports are used, evaluate potential movement at connections and junctures between different parts.
- Don't use EIFS cladding as a window sill or roof parapet flashing.
- Ensure that drainage from other surfaces does not flow over the EIFS finish, and that icicles will not form on it.
- Do not use EIFS where snow will be in contact with the finish for extended periods of time.
- On edges of soffits and undersides of EIFS projections, provide drips (grooves or other breaks), to cause surface water to fall free, rather than wetting and staining under surfaces.
- Cure EIFS materials a minimum of 24 hours at temperatures above 5 °C.
- Promptly repair damage to EIFS to prevent ingress of moisture.

were the prime reasons for these failures. (The cracking and delamination problems associated with these failures are further described later in this paper. Additional details are presented in a USACERL Technical Report [6].)

INVESTIGATION OF INSTALLED SYSTEMS

As a result of the previously mentioned failures at the two different installations, concerns were raised regarding the quality of EIFS as a wall cladding system. Funding was obtained to investigate the performance of EIFS that had been applied to facilities at other Army installations. Close to a hundred different buildings at several different Army and Air Force installations were examined. The observed successes and problems are described below.

EIFS Successes

Given the number of EIFS applications versus the few major problems reported to date, the use of EIFS on Army and Air Force facilities currently can be considered successful. The field assessments showed that EIFS had been effectively used to upgrade both the appearance and energy efficiencies of most of the buildings on which the system was applied. Only one location was observed where catastrophic system failures had occurred (Figure 3). These system delaminations were determined to be a result of poor workmanship and not an inherent problem of the system.

Observed Problem Areas

Even though only one catastrophic system failure was noted, system problems or deficiencies were observed at every location. The most common problems observed were cracking of the lamina and impact damage. Examples of poor workmanship were common. Problems were also seen as a result of poor design choices; such as, use of EIFS on a loading dock.

Cracking

Cracking of the lamina was observed at virtually every location. System cracking ranged from minor hairline cracks to cracks up to 9.5 mm (3/8 in.) wide. Most of the cracking occurred at corners and window and door penetrations. The majority of the cracking observed was a result of installers not properly abutting the insulation boards as can be seen in Figure 4. Gaps of up to 12.5 mm (½ in.) wide were found. In a few cases, cracks originated from the corners of windows and doors were a result of missing diagonal strips of mesh at the corners. Either the mesh strips were omitted during installation or the system was installed prior to when this procedure became a manufacturer recommended practice.

Impact Damage

Damage to the system due to mechanical impact must be considered a major problem. Evidence of impact damage was common. Impact damage was seen on both Class PB and Class PM systems. Although some of the damage was due to unintentional impact, intentional acts of vandalism (e.g., throwing rocks or kicking with boots) were the most common (Figure 5). Having an EIFS that is resistant to expected in-service impact exposures is considered to be a very important system quality. A lamina damaged due to mechanical impact provides a potential path for water to enter the system. At minimum, the infiltrating water will degrade the insulation properties of the system. At worst, catastrophic damage to the substrate could result. A study conducted by USACERL [2], showed a tremendous range of values for impact resistance between various EIFS. Several different test methods were used to study these differences. A falling weight test method (different from the EIMA impact test method) and a falling ball test method were submitted to ASTM for consideration. Which of the various procedures to use and how each method relates to actual performance is not yet resolved within the industry.

Workmanship

Poor workmanship accounted for most system deficiencies. Improperly prepared substrate surfaces and insufficient adhesion contact area lead to the system delaminations shown in Figure 3. The use of incorrect backer rod (i.e., an open-cell rather than the specified closed-cell backer rod) caused sealant failures. Failure to properly abut the insulation boards lead to the system cracking shown in Figure 4. All of these were considered preventable if the contractor had followed the specifications and industry accepted installation practices.

Solutions

Most all of the system problems experienced were considered to be preventable. Greater than 90% of the system deficiencies could be attributed to poor workmanship. With proper inspection, most of the deficiencies could have been discovered in time to be corrected during initial construction. However, site inspectors need to be appropriately educated on what to look for that might lead to EIFS problems. Design issues including specifying the system in areas where it is not well suited (e.g., at a loading dock) or failure to specify high-impact systems in high-traffic areas, accounted for most of the other failures. A series of manuals was proposed to help provide this information to the Corps engineers specifying EIFS as well as the inspectors overseeing EIFS applications. A special report was developed jointly by Leo A. Daly, Kenney, Williams and Williams, Inc., the Omaha District Corps of Engineers, and USACERL to further provide information to field engineers responsible for EIFS installations [7].

structural steel beams/columns, etc.) are in place and ready to receive the cladding and framing assembly. For comparison purposes, it is assumed costs of the main structural components are identical, regardless of the cladding/framing assembly selected. Costs for structural/framing assemblies include labor and materials (i.e. gypsum wallboard and supporting framing if required) necessary to receive the interior finish. The cost of the framing assembly can vary widely depending upon the cladding and therefore is included in the analysis, although it is generally not considered to be a component of the cladding. Design of the framing assembly is based upon cladding requirements and local wind loads calculated as per The Guide to the Wind Load Provisions of ASCE 7-88 (formerly ANSI A58.1) [4]. The design evaluation considered wind load coefficient, building importance factor, deflection, spacing of the framing, and pullover values for sheathed substrates. For purposes of design, floor to floor heights were assumed to be ten feet (3 m) which is typical for a commercial building. The results of the design evaluation yields design wind loads on the components and claddings, along with the required moment capacity and required moment of inertia. All of the cladding assemblies were designed to meet the minimum thermal resistance requirements (R value of 12.5 $F \bullet ft^2 \bullet h/Btu$) of the local building codes [5]. However, some assemblies may slightly exceed the R value of 12.5 if commercially available materials and types could not achieve an exact 12.5 R value. These costs were considered since they can vary widely depending on the type of insulation utilized as well as the method of installation. The analysis also takes into consideration the reduction in R value of the wall assembly due to thermal bridging (for framed assemblies) as per the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE 90.1-1989: Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1-1989) [6]. Inside and outside air flows, and interior finishes were not included in the ASHRAE energy design due to their relatively low values with respect to the overall wall assembly and would have an insignificant overall cost impact.

COST/DATA

Estimated installation costs of the cladding and structural framing assembly shown in Table 2 were derived from nationally recognized construction cost data publications [7,8]. Nationally recognized publications were used to derive the cost since it was most desirable to use an unbiased source and costs representing national averages. The national average costs were adjusted with city cost indices to accommodate local conditions as indicated in the publication.

Estimated maintenance costs and frequencies were derived from sources such as consultation with various industry professionals, publications, as well as a nationally recognized facilities maintenance and repair cost data publication [9,10]. The latter item was not used as the sole source of the cost data since the reported accuracy is plus or minus 20% because of the wide range of maintenance tasks and diverse environments addressed by the publication. Consequently, multiple sources were utilized in an effort to enhance the reliability of the data.

All installation and maintenance cost data shown in Table 2 represent current dollar costs. Table 3 provides projected life cycle costs for each of the cladding and structural/framing assemblies. Although opinions may differ slightly with the cost data shown, it provides an overall relative comparison of the various wall system alternatives.

LIFE CYCLE COST CALCULATIONS

Net life cycle costs tabulated in Table 3 were calculated in present value terms. The analysis assumes a thirty year study period as it is a reasonable time frame for an investor-owned property. Projected annual discount and inflation rates were obtained from a national financial institution and assumed to be a constant 4-3/4% and 3% respectively over the entire study period. Tax benefits are based on a combined 40% federal and state tax rate. A thirty nine year straight-line depreciation period was used based on current tax law.

CONSTRAINTS

All of the claddings and framing assemblies considered are representative of typical construction methods and materials and are viable assemblies for the model considered. It should be understood that additional cladding and structural/framing options exist, however, they are outside the scope of this paper. Additionally, all of the claddings and structural/framing assemblies satisfy the same basic functional requirements (i.e. protect building occupants, contents, provide pleasing aesthetics, etc.), which is essential for comparison of the assemblies. The structural/framing assemblies are assumed to be located outboard of the slab resulting in an equivalent net rentable floor area for all wall system assemblies. Costs related to windows, doors, sealants, flashings, etc. were assumed to be similar regardless of the cladding alternative selected so they have not been considered in this analysis. The only exception is precast concrete which must be installed in prefabricated panels and therefore included the additional cost of sealant and related maintenance at the panel perimeters since it is not required by any of the other assemblies under consideration.

TABLE 2--Cost Data (Current Dollar Costs)

Cladding and Structural Framing Assembly	Estimated Initial Installation Costs[5] ($/ft^2)	Description of Maintenance[6]	Maintenance Costs and Frequencies[7]
Exterior Insulation and Finish Systems (Class PB) with metal stud framing	$234 086 ($11.43/ft^2)	Clean 100% of the EIFS	$9 421 at year 15
		Clean and recoat 100% of the EIFS	$18 432 at year 30
Stucco with metal stud framing	$216 269 ($10.56/ft^2)	Repair cracks in stucco, 2% of wall surface	$1 273 per 10 years
		Clean 100% of the stucco	$9 421 at year 15
		Clean and paint 100% of the stucco	$18 432 at year 30
Brick Veneer with metal stud framing	$416 973 ($20.36/ft^2)	Clean 100% of the brick Repoint 30% of the brick	$14 398 at year 25
Brick Face Cavity Wall with concrete block	$429 261 ($20.96/ft^2)	Clean 100% of the brick Repoint 30% of the brick	$14 398 at year 25
Stone Veneer with metal stud framing	$572 006 ($27.93/ft^2)	Clean 100% of the stone Repoint 30% of the stone	$14 398 at year 25
Precast Concrete panels with metal stud framing (non-loadbearing)	$357 886 ($17.47/ft^2)	Recaulk 100% of the panels	$30 925 at year 20
		General cleaning on 100% of panels	$9 421 at year 25
Reinforced Split Face Block Wall with metal stud framing (non-loadbearing)	$300 032 ($14.65/ft^2)	Clean 100% of the brick Repoint 30% of the brick	$14 398 at year 25

[5]See Appendix for maintenance and installation cost calculations.
[6]The cost of maintenance on a three story building will vary from floor to floor due to scaffolding costs. The costs noted for each cladding alternative is average of the costs for each floor.
[7]All maintenance costs assume a thirty year study period.

TABLE 3--Projected Life Cycle Cost (Present Value Dollars)

Cladding and Structural/ Framing Assembly	Estimated Installation & Maintenance Costs (Year)							Cash Outflow[8] (years 0-30)	Cash Inflow[9] (years 0-30)	Net Life Cycle Cost (Net cash outflow)
	0	5	10	15	20	25	30			
EIFS (Class PB)										
a) cash outflow (initial costs and maintenance)	234 086	0	0	7 318	0	0	11 119	252 523	0	
b) cash inflow (tax benefits)								0	41 813	210 710
Stucco										
a) cash outflow (initial costs and maintenance)	216 269	0	1 076	7 318	908	0	11 887	237 458	0	
b) cash inflow (tax benefits)								0	59 927	177 531
Brick Veneer										
a) cash outflow (initial costs and maintenance)	416 973	0	0	0	0	9 449	0	426 422	0	
b) cash inflow (tax benefits)								0	73 055	353 367
Brick Face Cavity Wall										
a) cash outflow (initial costs and maintenance)	429 261	0	0	0	0	9 449	0	438 710	0	
b) cash inflow (tax benefits)								0	74 574	364 136

[8]See Appendix for present value and tax benefit equations, sample calculations as well as methods to determine tax benefits.
[9]Total cash inflows (tax benefits) were provided for the thirty year study period.

TABLE 3--Projected Life Cycle Cost (Present Value Dollars) (cont.)

Cladding and Structural/ Framing Assembly	Estimated Installation & Maintenance Costs (Year)							Outflow[10]	Inflow[11]	Net Life Cycle Cost
	0	5	10	15	20	25	30	(years 0-30)	(years 0-30)	(Net cash outflow)
Stone Veneer a) cash outflow (initial costs and maintenance)	572 006	0	0	0	0	9 449	0	581 455	0	
b) cash inflow (tax benefits)								0	99 836	481 619
Precast Concrete a) cash outflow (initial costs and maintenance)	357 886	0	0	0	22 079	6 183	0	386 148	0	
b) cash inflow (tax benefits)								0	69 446	316 702
Reinforced Split Face Block a) cash outflow (initial costs and maintenance)	300 032	0	0	0	0	9 449	0	309 481	0	
b) cash inflow (tax benefits)								0	52 881	256 600

[10] See Appendix for present value and tax benefit equations, sample calculations as well as methods to determine tax benefits.
[11] Total cash inflows (tax benefits) were provided for the thirty year study period.