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REPORT TITLE: FINAL REPORT ON FIRE TESTING OF EPOXY REPAIRED SHEAR WALLS

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TECHNICAL NOTE

All stress values provided in this report are based on the gross cross-sectional area, ABEF, in Fig. A-1 regardless of the amount of epoxy burnout.

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16. Abstract (Limit: 200 words)

Experimental test results obtained from fire tests on small-scale, intermediate-scale, and large-scale epoxy repaired shear wall specimens are presented. The specimens were fabricated from ready-mixed concrete using a six-bag mix. The shear wall specimens were cured for approximately seven days prior to the formation of the crack. Six different structural epoxy adhesives were considered. All six are thermosetting resins derived from the oil refining intermediate products, epichlorhydrin and bisphenol A. Fillers were not added to the adhesives either before or during the injection of the adhesives into the cracks. These six epoxy adhesives were chosen because their chemical and physical properties are representative of most epoxies that have been or are being used for the repair of damaged structures since the 1971 San Fernando Earthquake. They have been divided into two groups: low viscosity and high viscosity epoxy adhesives.

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CHAPTER A: INTRODUCTION TO TESTING PROGRAM: PROCEDURE AND RESULTS

SEC. A.1: INTRODUCTION

This report presents the experimental test results obtained from fire tests on small-scale, intermediate-scale and large-scale epoxy repaired shear wall specimens. All experiments presented herein have been conducted at the Structures Laboratory of California State University, Long Beach and the University of California, Berkeley. The small-scale specimens are illustrated in Fig. A-1 with wall dimensions of 18 in. x 14 in. The intermediate-scale and large-scale specimens are discussed in Chapters K, L and M with wall dimensions of 40 in. x 34 in. and 102 in. x 90 in. as shown in Fig. A-1. Test results for small-scale specimens are presented in Chapters B through J. The discussions in Chapter A pertain to small, intermediate and large-scale specimens.

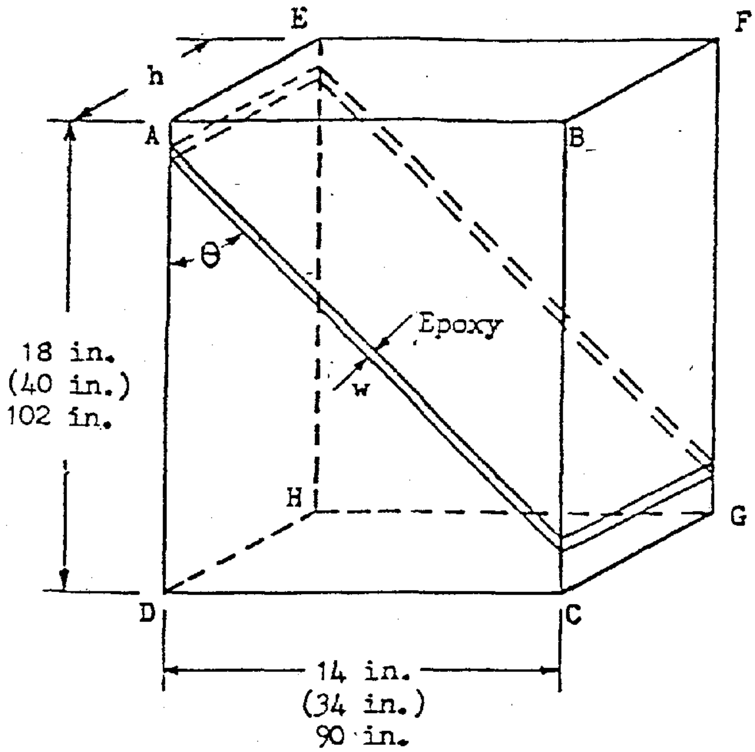

Fig. A-1: General Specimen Configurations

SEC. A.2: CONCRETE SPECIMEN PREPARATION

Fig. A-1 provides the dimensions for all wall specimens used in this research program. The most important specimen parameters studied include wall thickness, h, and crack width, w. The specimens were constructed with wall thickness of 6 in., 8 in., and 10 in. The crack widths studied included 0.05 in., 0.10 in., and 0.25 in.

The specimens were fabricated from ready mixed concrete using a 6 bag mix. Rounded aggregate with a 3/4 in. maximum size and Type I Portland Cement were used for the construction of all specimens. Control cylinders were prepared and tested in accordance with ASTM C39 "Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens". The average 28 day compressive strength of the control cylinders was 4.15 ksi with a standard deviation of 0.36 ksi.

The shear wall specimens illustrated in Fig. A-1 were cured for approximately seven days prior to the formation of the crack. To simulate actual crack surfaces of concrete shear walls, each shear wall specimen was broken as a beam at an angle θ equal to 45°. Since compression loads were applied to the top and bottom surfaces (ABFE and CDGH in Fig. A-1), this crack configuration provided maximum shear stresses within the epoxy repaired crack. The concrete shear wall specimens, having been broken into halves, were cured for a minimum of at least 90 days prior to epoxy injection. The cracked specimens were cured under laboratory conditions, that is, temperature of 70°F and relative humidity of 50%. After the 90 day curing period, the specimens were injected with appropriate epoxy adhesives as described in Sec. A-4. Sec. A-9 discusses the moisture content in concrete and plaster at the time of fire testing.

SEC. A.3: EPOXY ADHESIVES USED IN THE EXPERIMENTAL PROGRAM

Six different structural epoxy adhesives were considered in this research program. All six epoxy adhesives are considered thermosetting resins derived from the oil refining intermediate products; epichlorhydrin and bisphenol A. Fillers were not added to the epoxy adhesives either before or during the injection of the adhesives into cracks. These six epoxy adhesives were chosen because their chemical and physical properties are representative of most epoxies that have been or are being used for the repair of damaged structures since the 1971 San Fernando Earthquake. Based on technical data provided by the manufacturers of epoxy adhesives and additional experimental work on the physical properties of these epoxy adhesives at the Structures Laboratory, all six epoxy adhesives have been divided into two groups: low viscosity and high viscosity epoxy adhesives. The low viscosity epoxy adhesives were obtained from four manufacturers including Delta Plastics Co., Visalia, Ca.; Hunt Process Co., Santa Fe Springs, Ca.; IPA Systems, Philadelphia, Pa.; and Adhesive Engineering, San Carlos, Ca. The range of mechanical properties for epoxy adhesives supplied by these four manufacturers are as follows:

Viscosity (cps)	300 - 800
Compressive Strength at 70°F (psi)	12,000 - 17,000
Tensile Strength at 70°F (psi)	7,000 - 12,000
Pot Life (minutes)	20 - 40
Heat Distortion Temperature (°F)	120 - 145
Strength Transition Temperature (°F)	220 - 240

Considerable variation in the strength properties of these low viscosity epoxy adhesives did not affect fire test results because the heat distortion and the strength transition temperatures were similar for all four epoxies. Hence, the test results for all four low viscosity epoxies in subsequent chapters are combined into a single group of results for low viscosity epoxy adhesives.

The high viscosity epoxy adhesives were obtained from two manufacturers: Delta Plastics Co., Visalia, Ca. and Sika Chemical Corp., Lyndhurst, New Jersey. The range of mechanical properties for two epoxy adhesives supplied by these two manufacturers are as follows:

Viscosity (cps)	12,000 - 17,000
Compressive Strength at 70°F (psi)	13,000 - 16,100
Tensile Strength at 70°F (psi)	6,500 - 7,800
Pot Life (minutes)	30 - 50
Heat Distortion Temperature (°F)	115 - 135
Strength Transition Temperature (°F)	230 - 245

Considerable variation in the strength properties of these two high viscosity epoxy adhesives did not affect fire test results because the heat distortion and the strength transition temperatures were similar for both epoxies. Hence, the test results for these two epoxy adhesives are combined in subsequent chapters into a single group of test results for high viscosity epoxy adhesives.

SEC. A.4: EPOXY INJECTION PROCEDURE AND EPOXY CURING

The epoxy resin and hardner for all six epoxy adhesives were mixed together in proportions specified by the respective manufacturers. The hardner and resin were mixed together in quantities of up to 12 ozs. with the aid of a high speed drill. The epoxy was either injected into the cracks at pressures below 100 psi or simply poured into the crack whenever possible. All cracks were sealed with reinforced plastic tape and casting plaster which were both completely removed when the epoxy adhesive had cured. Since the cracked surfaces for all concrete specimens were formed as described in Sec. A.3, cleaning of the cracks was not required. At the time of the epoxy injection, all cracks were dry. Prior to any type of experimental testing, all epoxy adhesives were allowed to cure for a minimum of seven days. Visual observations accompanied by hardness tests for some specimens were used to insure proper curing of the epoxy adhesives.

SEC. A.5: DESCRIPTION OF ASTM AND SDHI FIRE EXPOSURES: HOT STRENGTH AND RESIDUAL STRENGTH

The epoxy repaired shear wall specimens described in the succeeding chapters were subjected to "pseudo-fire exposures" designed to simulate two different types of building fires. The two-hour duration ASTM E119 fire exposure for shear walls attempts to model a long duration fire with constantly increasing temperature, so that the cool down behavior is not represented. A short duration high intensity (SDHI) fire which peaks at about 0.2 hours, has a rapid temperature drop for a period of 0.4 hours and is followed by a slow cooling to room temperature. This SDHI time-temperature curve has been proposed by Professor Boris Bresler of U. C. Berkeley. Both the ASTM and the SDHI time-temperature curves are provided in Fig. A-2. As indicated by the results in subsequent chapters, the ASTM E119 type fire exposure is far more severe than the SDHI type on the fire rating of epoxy repaired structures.

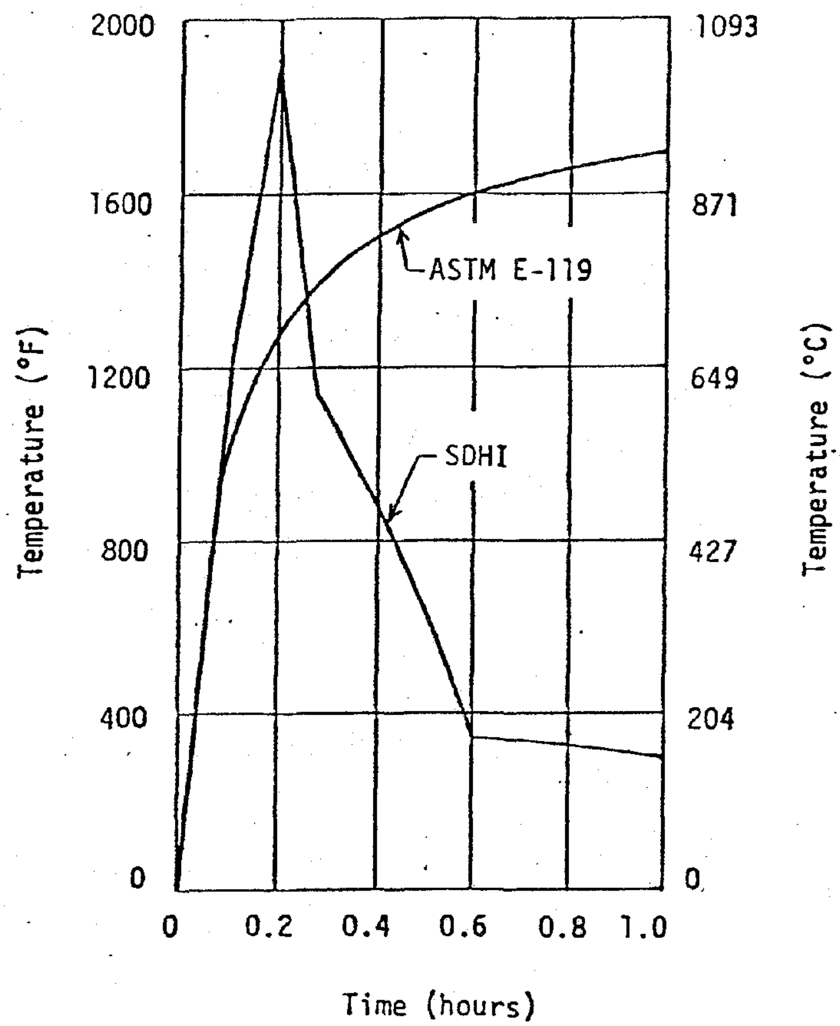

Fig. A-2: ASTM E119 and SDHI Time-Temperature Fire Curves

During fire exposure, the small-scale specimens were not subjected to any type of external loads. However, upon completion of the fire exposure, "hot strength" and "residual strength" compression tests were conducted. "Hot strength" type of tests refer to epoxy repaired small-scale specimens which were subjected to compression loads about 10 minutes after the end fire exposure. "Residual strength" tests refer to epoxy repaired small-scale specimens that were subjected to fire exposure, allowed to cool in a laboratory environment (70°F and 50% relative humidity) for a period of seven days, and then subjected to compression loads. As indicated in later chapters "residual strengths" of epoxy repaired shear walls were significantly higher as compared to "hot strengths". Sec. A.8 illustrates the behavior of pure epoxy adhesives at elevated temperatures. The strength properties of epoxy adhesives at elevated temperatures provide the explanation for the behavior of "hot strength" test results in subsequent chapters.

SEC. A.6: FIRE SURFACE COATINGS

Relatively low ultimate strength results in Chapter B for epoxy repaired specimens subjected to ASTM E119 fire exposure prompted a search for effective fire surface coatings which would decrease the depth of epoxy burnout and increase both the hot and residual strengths. Therefore, a series of surface coatings were applied to the fire surface for the purpose of investigating fire protection. These surface coatings were grouped into three categories including (1) gypsum plaster, (2) thin inorganic surface coatings and (3) thin organic surface coatings.

Gypsum plaster was mixed and applied to the fire exposed surfaces according to the appropriate specifications in the 1976 UBC. Total plaster thickness of 1 in. (7/8 in. thick base coat with sand aggregates and 1/8 in. thick finish coat) or 3/8 in. (1/4 in. thick base coat and 1/8 in. thick finish coat) were applied to the fire exposed surfaces. The plaster was allowed to cure for at least 30 days prior to fire testing. The UBC specifies a minimum plaster thickness of 1/2 in. for fire protection. However, the 3/8 in. plaster thickness was used in this experimental program in order to determine the minimum plaster thickness which may be effective in reducing the depth of epoxy burnout. Moisture content in the plaster at the time of fire testing is discussed in Sec. A-9.

Thin inorganic surface coatings were also applied to the fire exposed surface in thicknesses of 0.050 in. and 0.100 in. These inorganic coatings consisted of a one to one mixture on volume basis of sodium silicate and Type I Portland Cement. This inorganic coating was applied to the fire surface with a trowel and cured a minimum of seven days prior to fire exposure. The fire test results showed that this type of thin inorganic surface coatings are ineffective. Thin organic surface coatings were also applied to the fire surfaces in the form of "fire resistant epoxy foams" and fire retardant intumescent paints. The thickness of these coatings included 0.050 in. and 0.100 in. and were applied to the fire surface with a trowel. These inorganic surface coatings were cured for a minimum of seven days prior to fire testing. The test results for those organic surface coatings are provided in Chapter I.

SEC. A.7: DESCRIPTION OF TEST PROCEDURE

All fire tests were conducted in the natural gas furnaces at California State University, Long Beach and U.C. Berkeley. After the specimens were fully prepared, that is, the injected epoxy had been cured for a minimum of seven days and fire surface coatings applied whenever required, the specimens were placed in the furnace with only one surface (surface ABCD in Fig. A-1) exposed to the fire.

During the fire exposure, loads were not applied to the small scale specimens. The intermediate and large-scale specimens were tested with bearing loads as indicated in Chapters K, L, and M. Immediately after the fire exposure, the specimens were removed from the furnace and subjected to the compression load until failure in the case of "hot strength" tests. The ultimate compressive stress data provided in subsequent chapters refers to the maximum stress applied to the specimen during the complete load cycle at a loading rate similar to that specified in ASTM C39. The depth of epoxy burnout was determined for each specimen immediately after the specimen had failed under compression loading. The "residual strength" tests were conducted according to the test procedure described in Sec. A.5. Chapter J provides the test procedure and repair procedure for specimens subjected to fire exposure, cooled at room temperature, repaired with epoxy and cement and subsequently tested in compression. All stress data is given in terms of the applied load divided by the cross-sectional area of plane ABEF in Fig. A-1.

SEC. A.8: STATIC STRENGTH PROPERTIES OF LOW VISCOSITY EPOXY ADHESIVES AT ELEVATED TEMPERATURE

This section provides a brief explanation of a series of test results on low viscosity epoxy adhesives exposed to elevated temperatures and conducted at the Structures Laboratory. An electric convection oven was used for uniform temperature control and all loads were applied statically with the MTS Dynamic Testing Machine. For compressive strength tests, the test procedure including the loading rate and specimen geometry (cylinders with 1/2" diameter and 1" length) were obtained from ASTM D-695 with the following exceptions. Each cylindrical specimen was placed in the pre-heated electric oven for a period of one hour at a specified uniform temperature. For the "hot test", the specimens were removed from the oven and immediately subjected to a static compressive load. Curve I in Fig. A-3 illustrates the "hot test" results for static compressive strength. Beyond 400°F the "hot" compressive strength is negligible due to cracking and rubber-like behavior of the specimens which results in reduced strength properties. The "residual test" specimens for static compressive strength were also subjected to a one-hour temperature exposure, cooled under laboratory conditions for about seven days, and subsequently tested in pure compression. Curve II in Fig. A-3 provides the "residual test" results for static compressive strength. For temperature exposures of up to 300°F, the "residual compressive strength" did not change appreciably. Beyond 400°F temperature exposures, the specimens usually cracked and became rubber-like resulting in low "residual" compressive strength properties. Since the compressive tests utilized laterally unconfined specimens, the "residual" strength properties of structural epoxy adhesives confined within thin cracks may be considerably different from those indicated in Fig. A-3 especially at temperatures near and above 400°F.

Curve I in Fig. A-3 also illustrated a drastic change in the mechanical properties in the temperature range of 200°F to 250°F. Due to the sudden drop in the "hot" strength properties at a temperature of about 230°F, this temperature is herein defined as the strength transition temperature, T_s. Curve II also shows that the maximum residual strength is achieved at temperatures near the strength transition temperature (230°F) rather than the heat distortion temperature (136°F). These results are substantiated by the thermodynamic concepts of cure or polymerization which state that the optimum post cure temperatures are near the glass transition temperature.

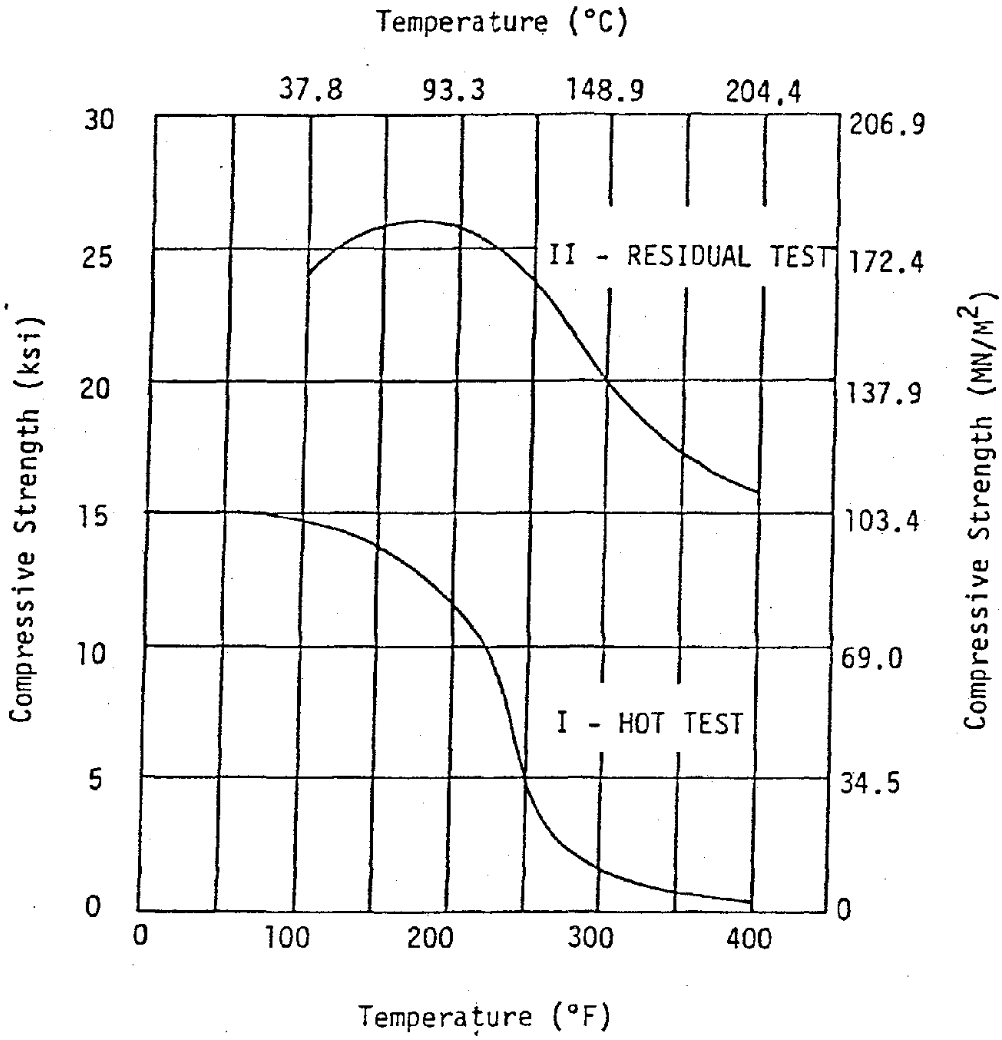

Figure A-3. Compressive Strength of Low Viscosity Epoxy Adhesives

SEC. A.9: MOISTURE CONTENT STUDIES

All moisture contents were obtained by weight at a temperature of 220°F for periods of approximately 10 hours (ASTM D2016). The moisture contents for both concrete and plaster were generally obtained within 3 days prior to fire exposure. The small-scale specimens were cured in a laboratory environment (70°F and 50% relative humidity) for time periods not less than 140 days but not more than 180 days prior to fire exposure. The moisture content of concrete in small scale specimens varied from 1.4% to 1.8%. The plaster coating applied to the small scale specimens was also analyzed for moisture content prior to fire exposure with results varying from 1.6% to 2.0%. The intermediate and large scale specimens were constructed and cured under laboratory conditions at CSULB for a period of about 90 days. These specimens were transported to UC Berkeley Richmond Field Station by truck. These specimens were placed outside of the laboratory and covered with polyethlene film. Despite this protection, several severe storms resulted in extensive absorption of moisture by both the plaster and concrete. The moisture contents for intermediate scale specimens in the plaster are provided in Chapter L and summerized below.

Specimen No.	Moisture Content in Plaster Base Coat (%)	Moisture Content in Plaster White Surface Coat (%)
G-1	2.1	5.7
G-3	2.1	12.4
G-4	2.1	10.9
G-5	2.1	9.6
G-6	2.2	9.5
G-7	2.0	10.4
Average	2.1	9.8

The moisture content in concrete varied from 2% to 3% in the intermediate scale specimens. For the large Scale specimens, the moisture contents in the plaster are provided in Chapter M with results summarized below.

Specimen No.	Moisture Content in Plaster Base Coat (%)	Moisture Content in Plaster White Surface Coat (%)
G-9	2.2	10.9
G-10	3.5	13.7

The moisture content in concrete varied from 2.5% to 3.3% in the large-scale specimens.

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CHAPTER B: SMALL SCALE ASTM E119 HOT STRENGTH COMPRESSION TESTS (NO FIRE SURFACE COATING; LOW VISCOSITY EPOXY)

SEC. B.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in this Chapter B have been exposed to the standard two-hour ASTM E119 fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in. and 0.25 in. and wall thicknesses of 6 in., 8 in., and 10 in. All specimens have been subjected to ultimate compression loads immediately after the two-hour fire exposure.

SEC. B.2: SUMMARY OF TEST RESULTS

Tables B-1, B-2, and B-3 provide the test data for each specimen including the ultimate compression strength and the depth of epoxy burnout. Figs. B-1, B-2, and B-3 provide the graphical summary of average test results including average ultimate compressive stress and depth of epoxy burnout as a function of crack width. Fig. B-4 provides a complete summary of test results for average ultimate compressive stress and average depth of epoxy burnout as a function of wall thickness. Fig. B-5 provides a pictorial view of a typical failure pattern for specimens tested in this chapter. The failure pattern for all specimens, including 6 in., 8 in. and 10 in. shear wall specimens, consisted of shear failure in the epoxy since the temperatures within the specimens during the compression tests were above the heat distortion temperatures. Ultimate compressive stress is a function of crack width due to the development of higher frictional forces between concrete surfaces in the case of smaller crack widths. Depth of epoxy burnout is not significantly affected by crack width.

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SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot strength Compression test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: None

TABLE B-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.76	0.625	2.68	0.423	2.95	0.060
2	2.76	0.798	2.76	0.693	2.76	0.060
3	2.36	0.902	2.95	0.536	3.15	0.060
4	2.76	0.798				
Average	2.66	0.781	2.80	0.550	2.95	0.060
Standard Deviation	0.20	0.115	0.14	0.136	0.20	0.000

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The following graphs illustrate the test results provided on page B-2 in TABLE B-1.

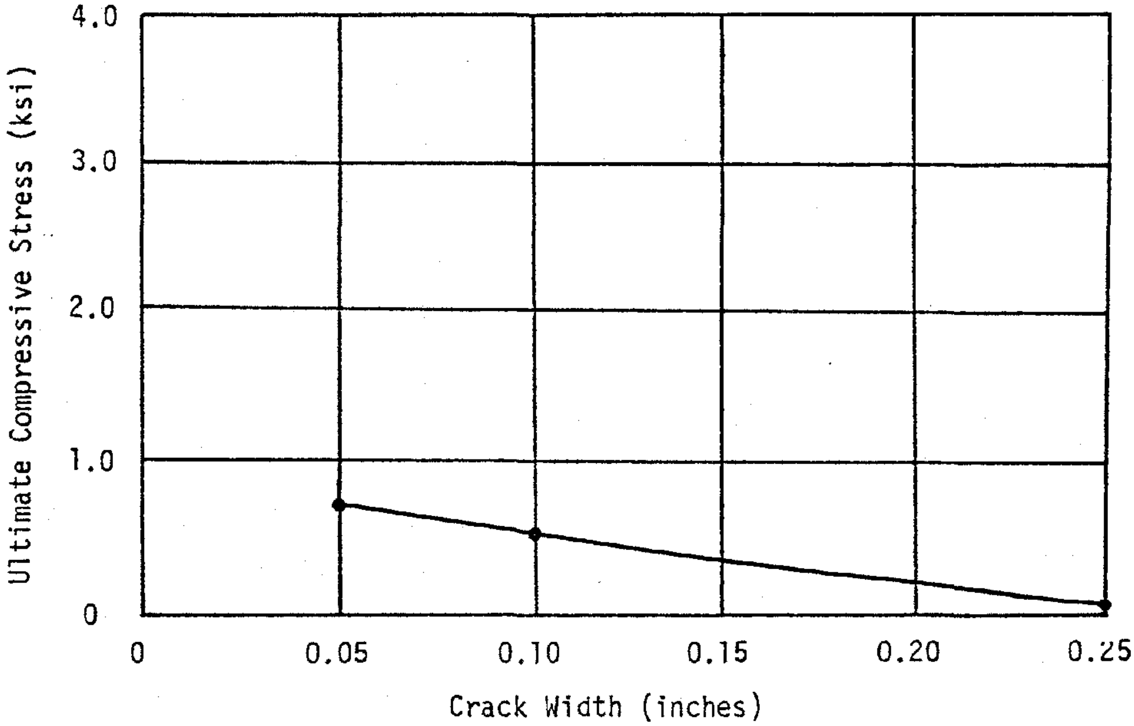

Fig. B-1a : Average Ultimate Compressive Stress as a Function of Crack Width

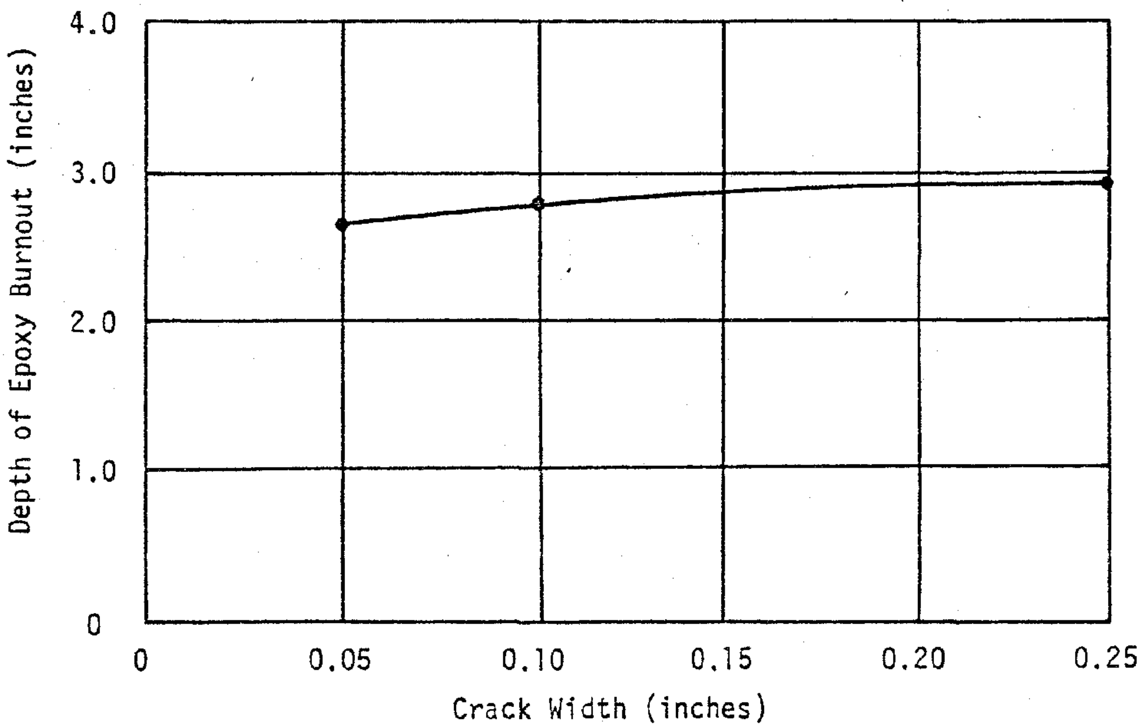

Fig. B-1b : Average Depth of Epoxy Burnout as a Function of Crack Width

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 8 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot strength Compression test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: NONE

TABLE B-2

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.56	0.830	2.76	0.481	3.35	0.146
2	2.95	0.469	2.76	0.520	3.07	0.210
3	2.36	0.729	2.76	0.491	3.15	0.182
4						
Average	2.62	0.676	2.76	0.497	3.19	0.179
Standard Deviation	0.30	0.187	0.00	0.020	0.14	0.032

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The following graphs illustrate the test results provided on page B-4 in TABLE B-2.

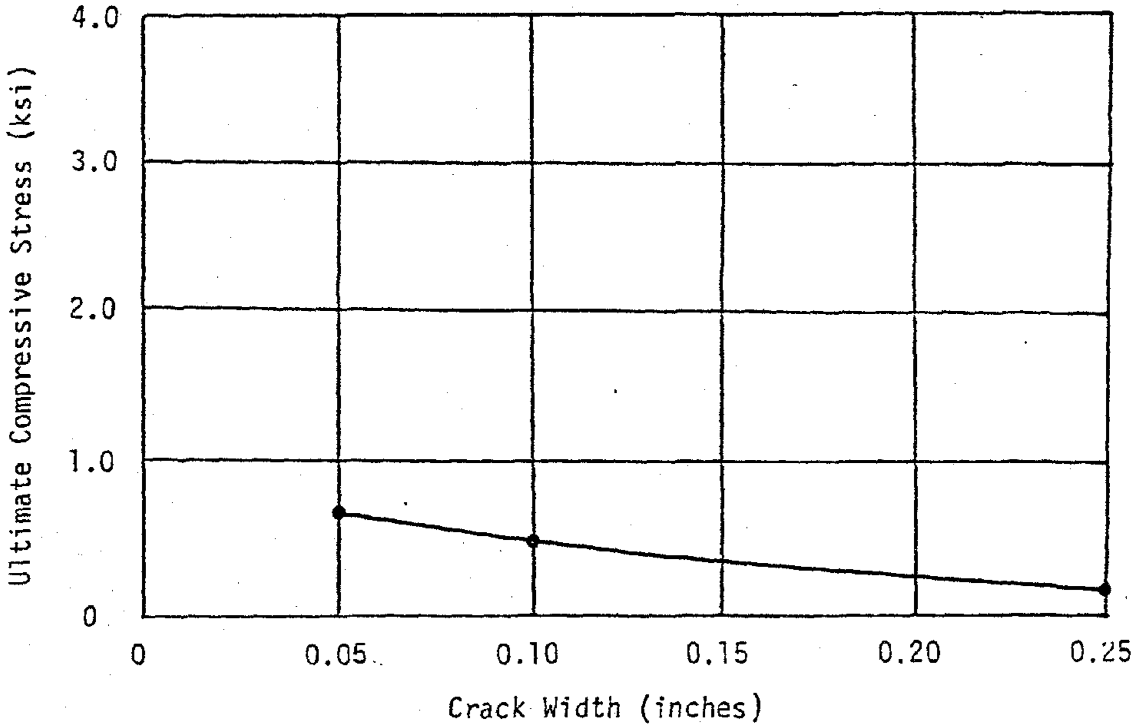

Fig. B-2a : Average Ultimate Compressive Stress as a Function of Crack Width

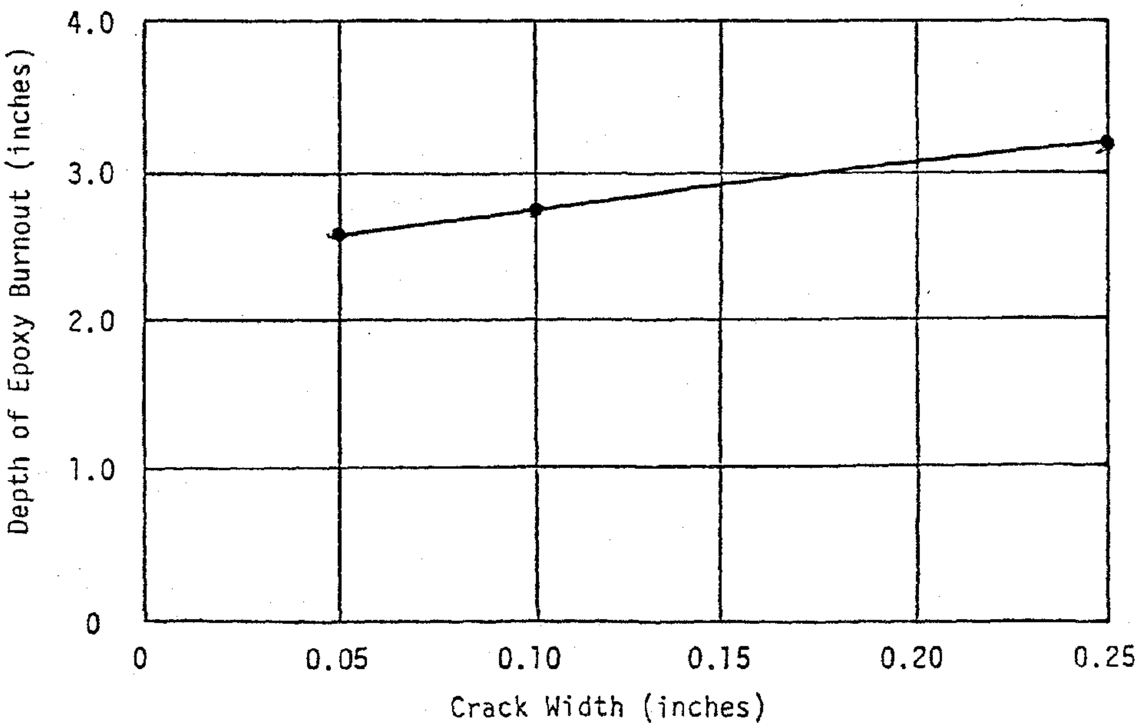

Fig. B-2b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 10 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot strength Compression test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: None

TABLE B-3

Specimen Number	Crack Width (inches) 0.05 Burnout (inches)	0.05 Ultimate Compressive Stress (ksi)	0.10 Burnout (inches)	0.10 Ultimate Compressive Stress (ksi)	0.25 Burnout (inches)	0.25 Ultimate Compressive Stress (ksi)
1	1.97	1.000	2.95	0.660	2.76	0.520
2	1.77	0.877	2.91	0.510	2.95	0.430
3	1.77	0.920	2.76	0.570	2.91	0.410
4						
Average	1.84	0.936	2.87	0.582	2.87	0.455
Standard Deviation	0.11	0.062	0.10	0.078	0.10	0.057

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The following graphs illustrate the test results provided on page B-6 in TABLE B-3.

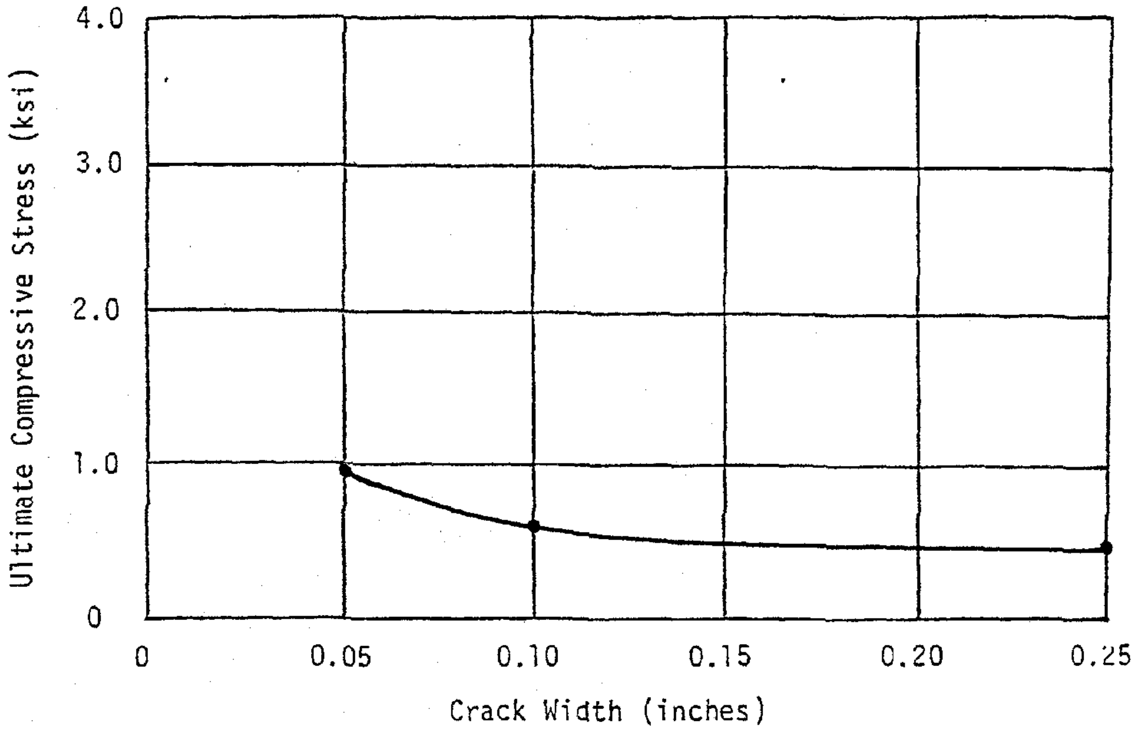

Fig.B-3a : Average Ultimate Compressive Stress as a Function of Crack Width

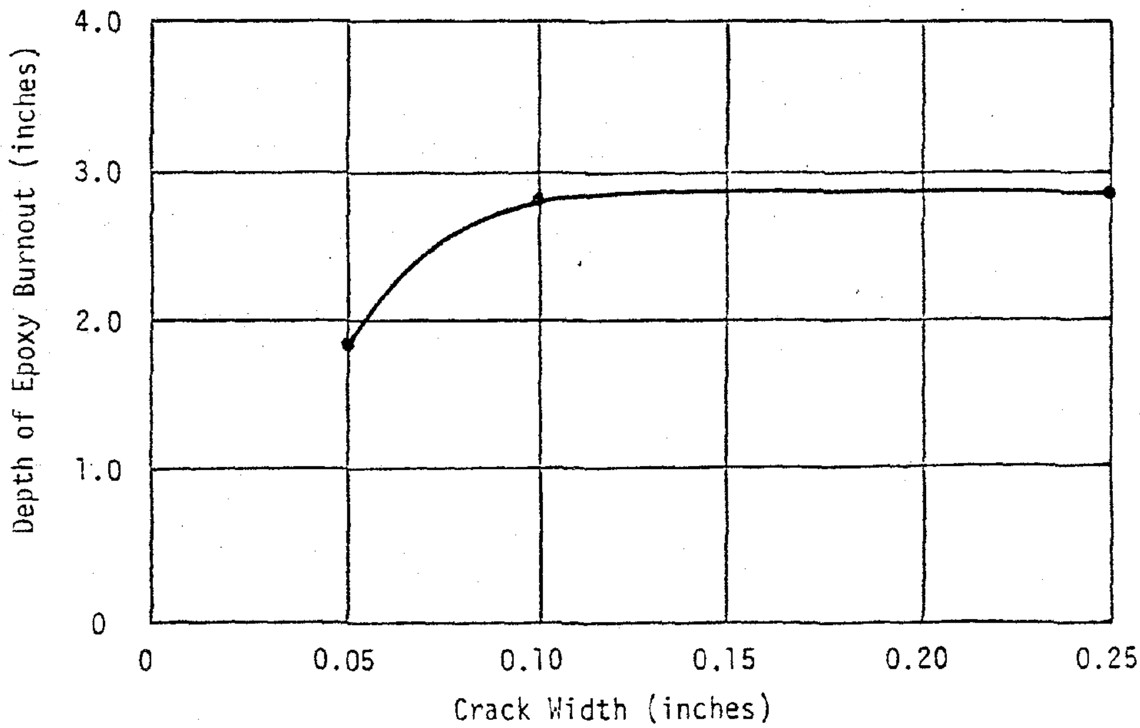

Fig.B-3b : Average Depth of Epoxy Burnout as a Function of Crack Width

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These graphs illustrate the average test results provided in TABLES B-1,B-2,B-3 as a function of specimen wall thickness for various crack widths.

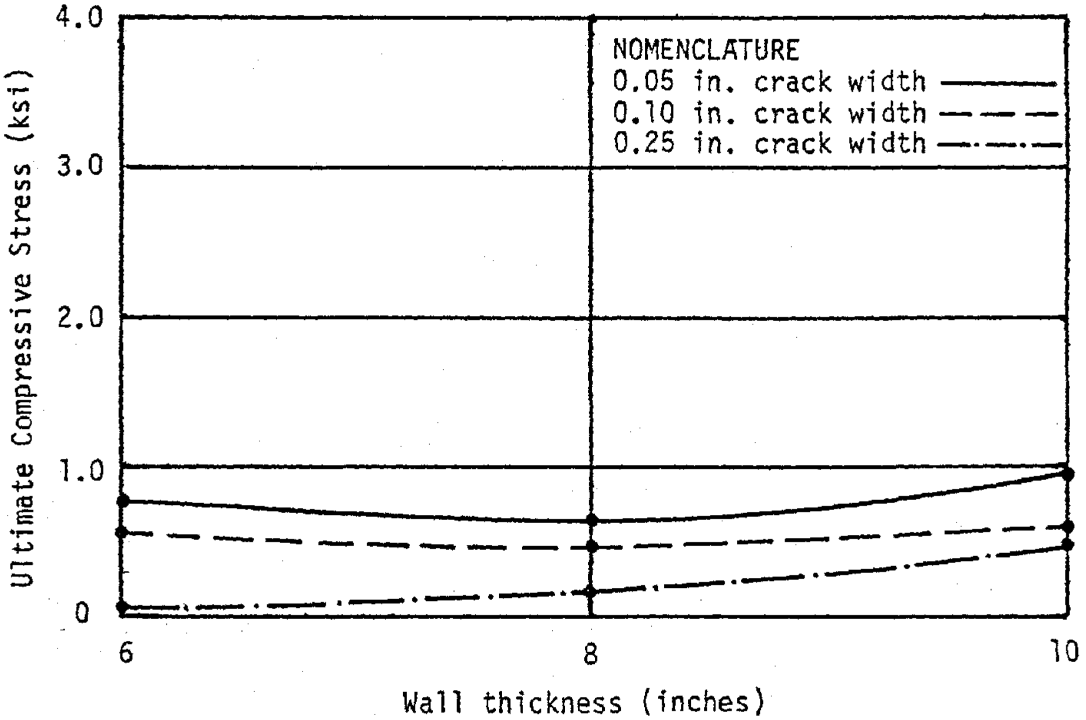

Fig. B-4a : Average Ultimate Compressive Stress as a Function of Wall Thickness

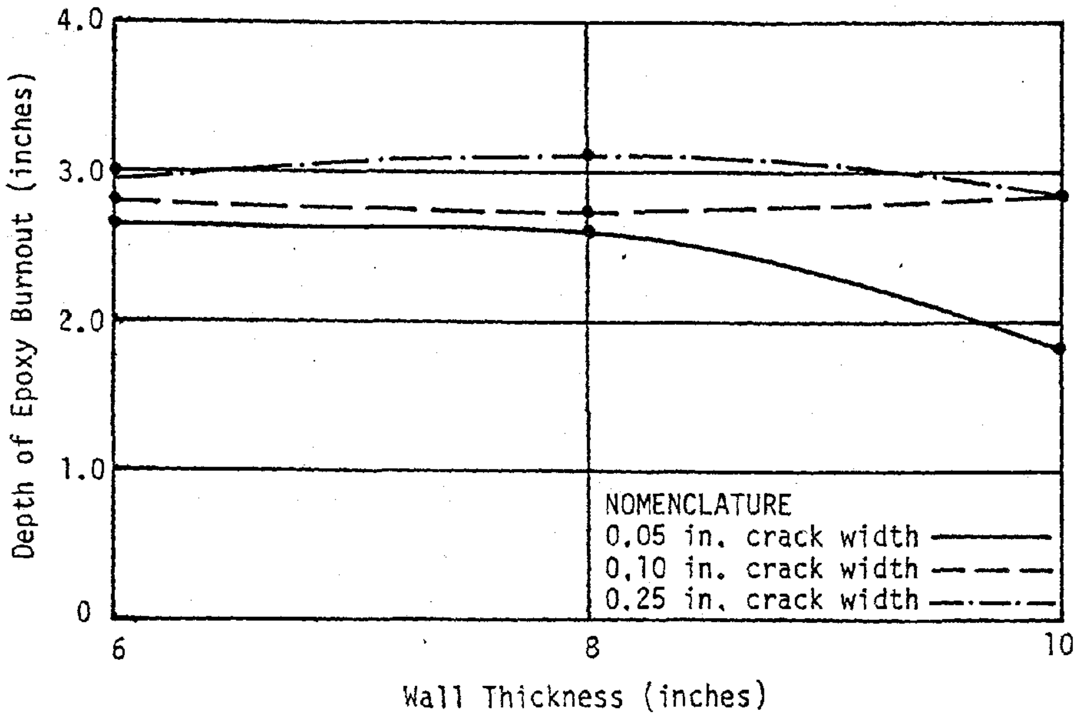

Fig. B-4b : Average Depth of Epoxy Burnout as a Function of Wall Thickness

Fig. B-5 : Failure pattern for 8 in. Thick Specimen.

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CHAPTER C: SMALL SCALE SDHI HOT STRENGTH COMPRESSION TESTS (NO FIRE SURFACE COATING: LOW VISCOSITY EPOXY)

SEC. C.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in this Chapter C have been exposed to the standard SDHI fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in., and 0.25 in. and wall thicknesses of 6 in., 8 in., and 10 in. All specimens have been subjected to ultimate compression loads after the fire exposure.

SEC. C.2: SUMMARY OF TEST RESULTS

Tables C-1, C-2, and C-3 provide the test data for each specimen including the ultimate compression strength and the depth of epoxy burnout. Figs. C-1, C-2, and C-3 provide the graphical summary of average test results including average ultimate compressive stress and depth of epoxy burnout as a function of crack width. Fig. C-4 provides a complete summary of test results for average ultimate compressive stress and average depth of epoxy burnout as a function of wall thickness. Fig. C-5 provides a pictorial view of a typical failure pattern for specimens tested in this chapter. Ultimate compressive stress is a function of crack width due to the development of higher frictional forces between concrete surfaces in the case of smaller crack widths. Depth of epoxy burnout is not significantly affected by crack width. The failure pattern for the 6 in. thick wall specimens consisted of shear failure in the epoxy since the temperatures within the specimens during the compression tests were above the heat distortion temperature. The failure pattern for most 8 in. and 10 in. shear wall specimens generally consisted of shear failure within concrete in regions where the epoxy was not burned out.

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot strength Compression test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE C-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress(ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0.79	0.762	1.18	0.489	1.10	0.423
2	0.69	0.920	0.98	0.850	0.98	0.658
3	0.79	0.693	0.79	0.455	0.98	0.351
4					0.87	0.524
Average	0.75	0.792	0.98	0.598	0.98	0.489
Standard Deviation	0.06	0.117	0.19	0.219	0.09	0.133

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page C-2 in TABLE C-1.

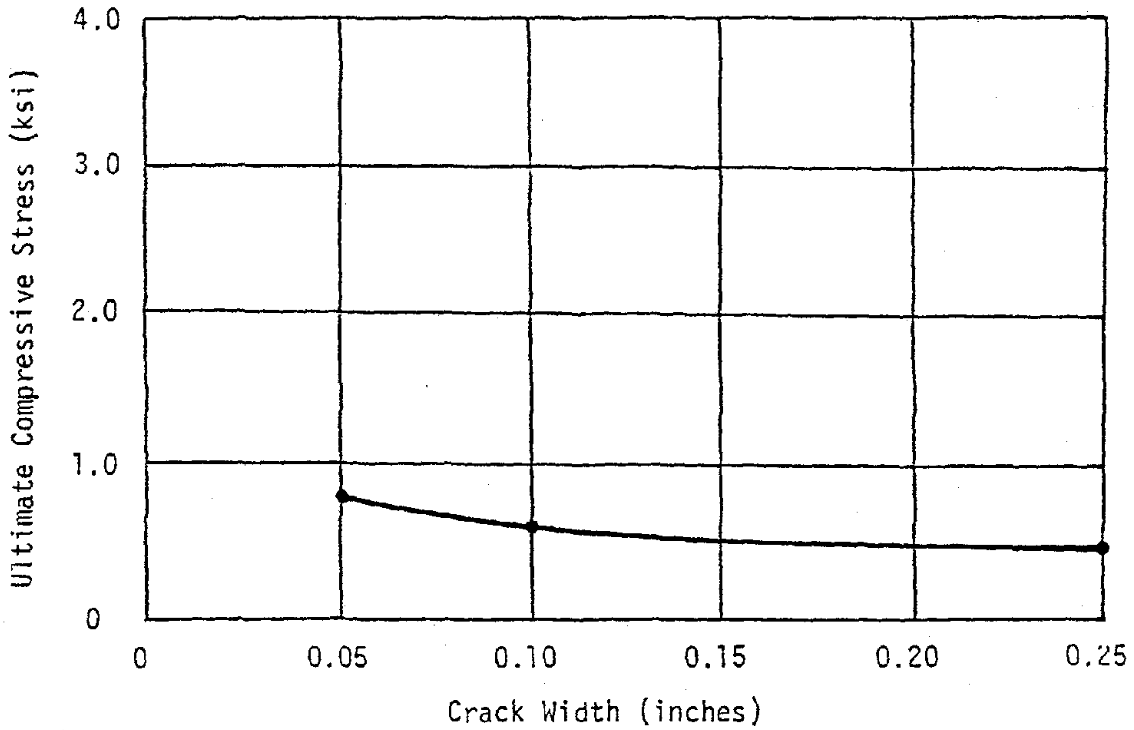

Fig. C-1a : Average Ultimate Compressive Stress as a Function of Crack Width

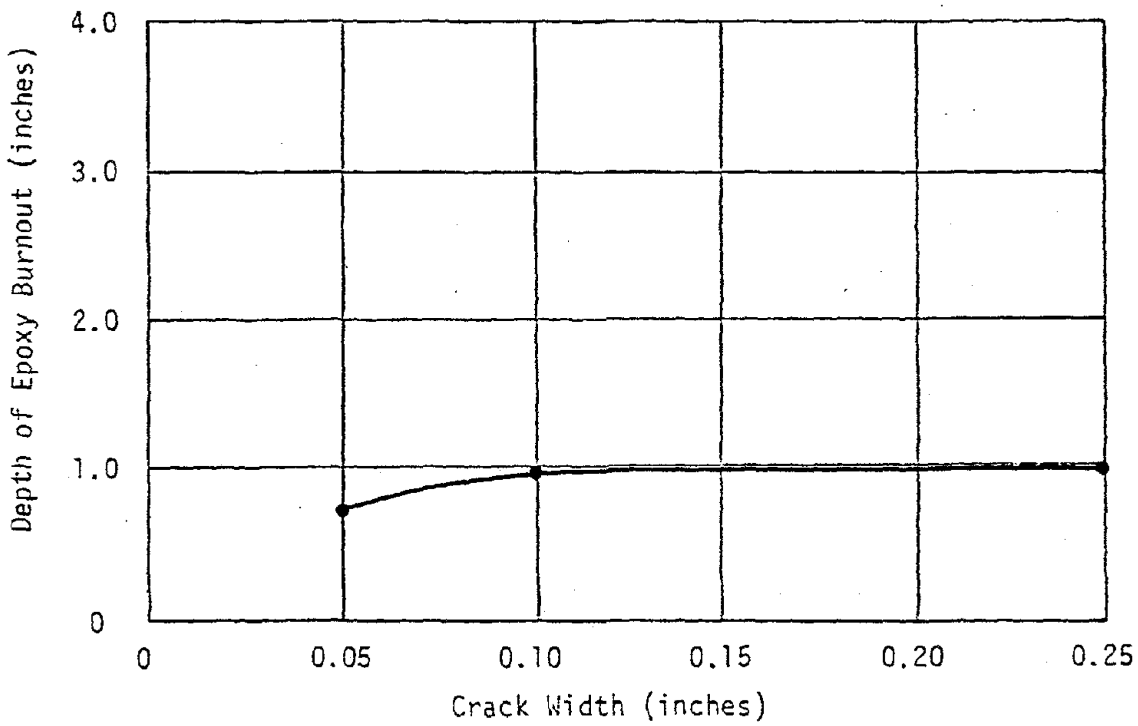

Fig. C-1b : Average Depth of Epoxy Burnout as a Function of Crack Width

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 8 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot strength Compression test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE C-2

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0.79	1.680	0.98	0.882	0.98	0.393
2	0.98	0.856	0.98	0.934	0.79	0.830
3	0.79	1.160	0.98	0.895	0.98	0.536
4						
Average	0.85	1.233	0.98	0.904	0.91	0.586
Standard Deviation	0.11	0.415	0.00	0.027	0.11	0.223

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page C-4 in TABLE C-2.

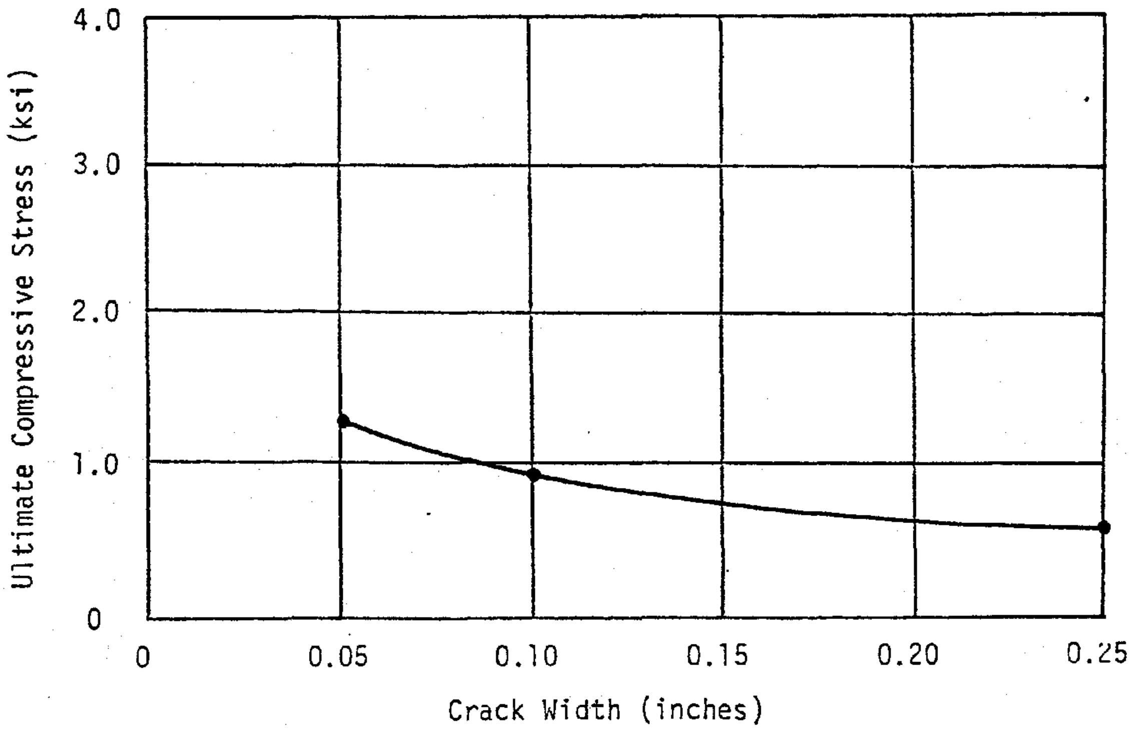

Fig. C-2a : Average Ultimate Compressive Stress as a Function of Crack Width

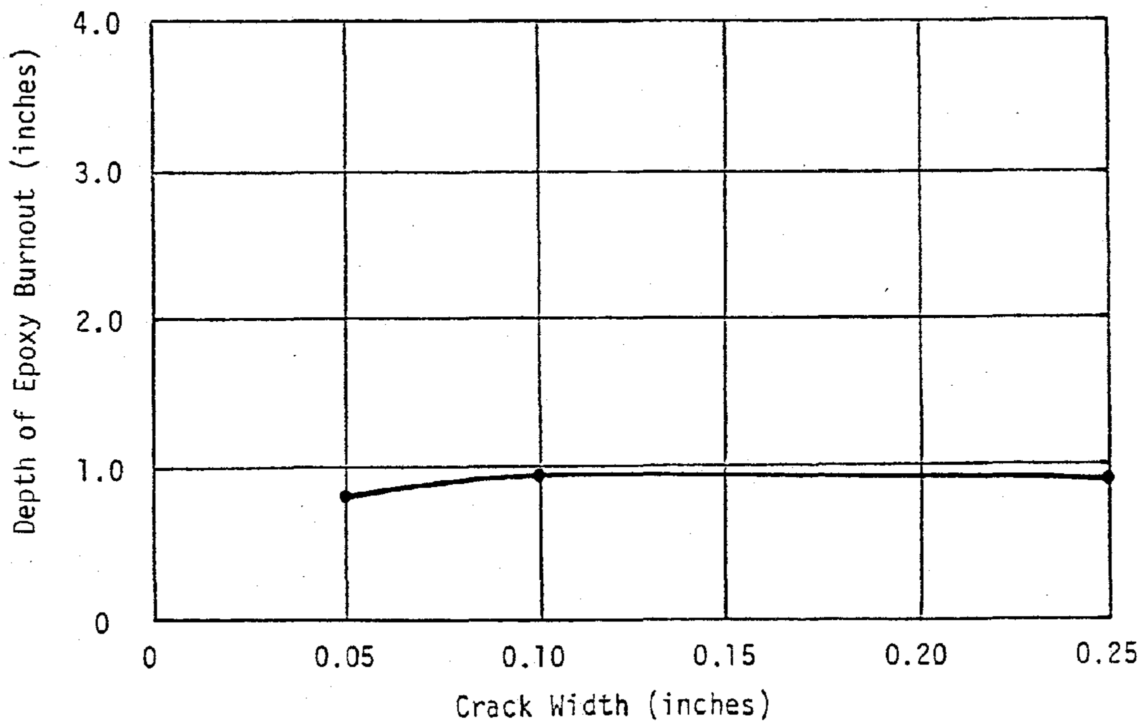

Fig. C-2b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 10 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot strength Compression test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE C-3

Specimen Number	Crack Width (inches) 0.05 Burnout (inches)	0.05 Ultimate Compressive Stress (ksi)	0.10 Burnout (inches)	0.10 Ultimate Compressive Stress (ksi)	0.25 Burnout (inches)	0.25 Ultimate Compressive Stress (ksi)
1	0.79	1.230	0.79	1.024	0.79	0.768
2	0.79	1.320	0.98	1.107	0.98	0.701
3	0.59	1.500	0.79	1.216	0.98	0.824
4						
Average	0.72	1.353	0.85	1.115	0.92	0.765
Standard Deviation	0.11	0.137	0.11	0.096	0.11	0.061

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page C-6 in TABLE C-3 .

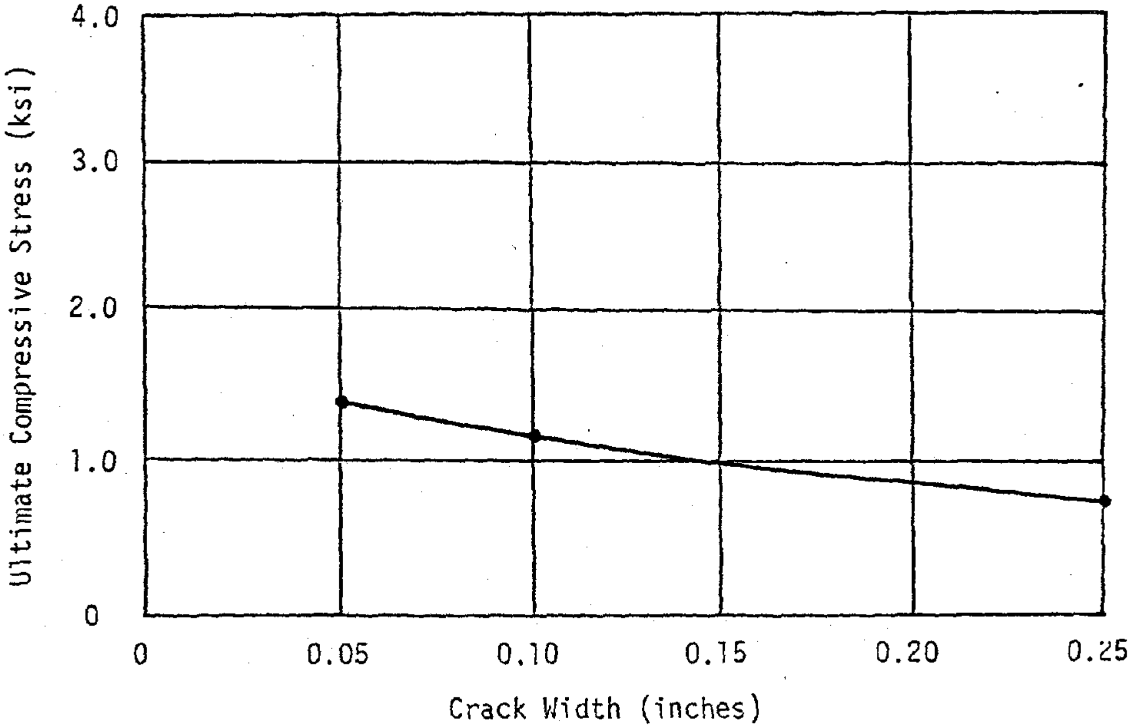

Fig. C-3a : Average Ultimate Compressive Stress as a Function of Crack Width

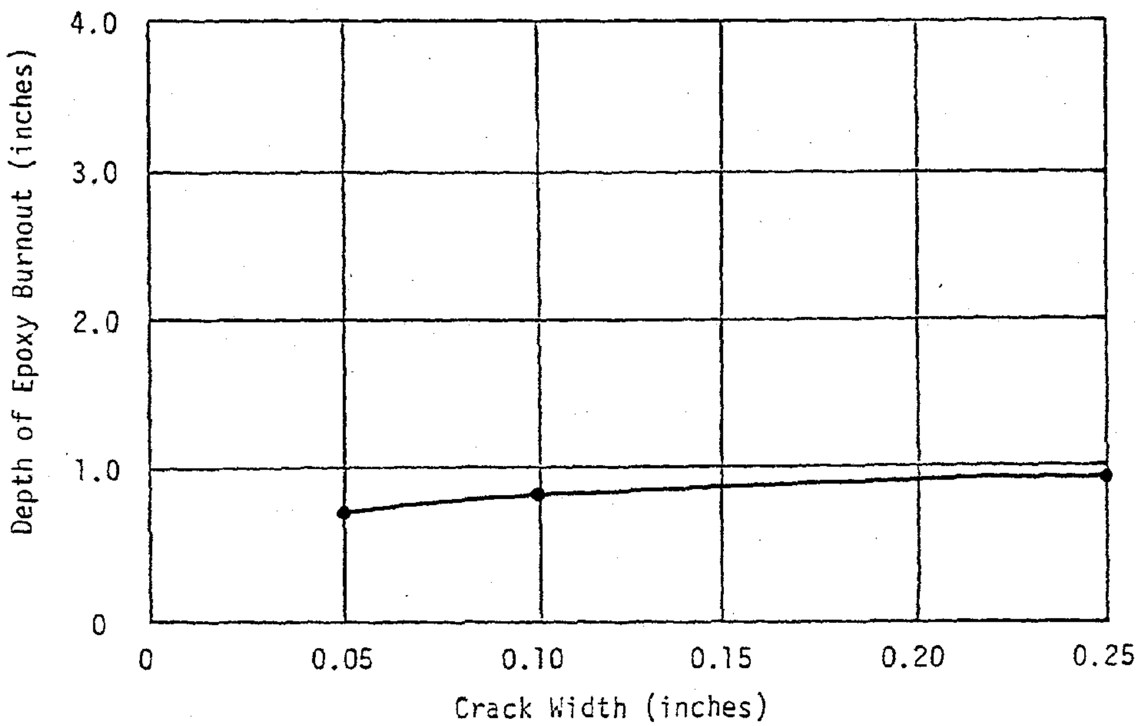

Fig.C-3b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

These graphs illustrate the average test results provided in TABLES C-1,C-2,C-3 as a function of specimen wall thickness for various crack widths.

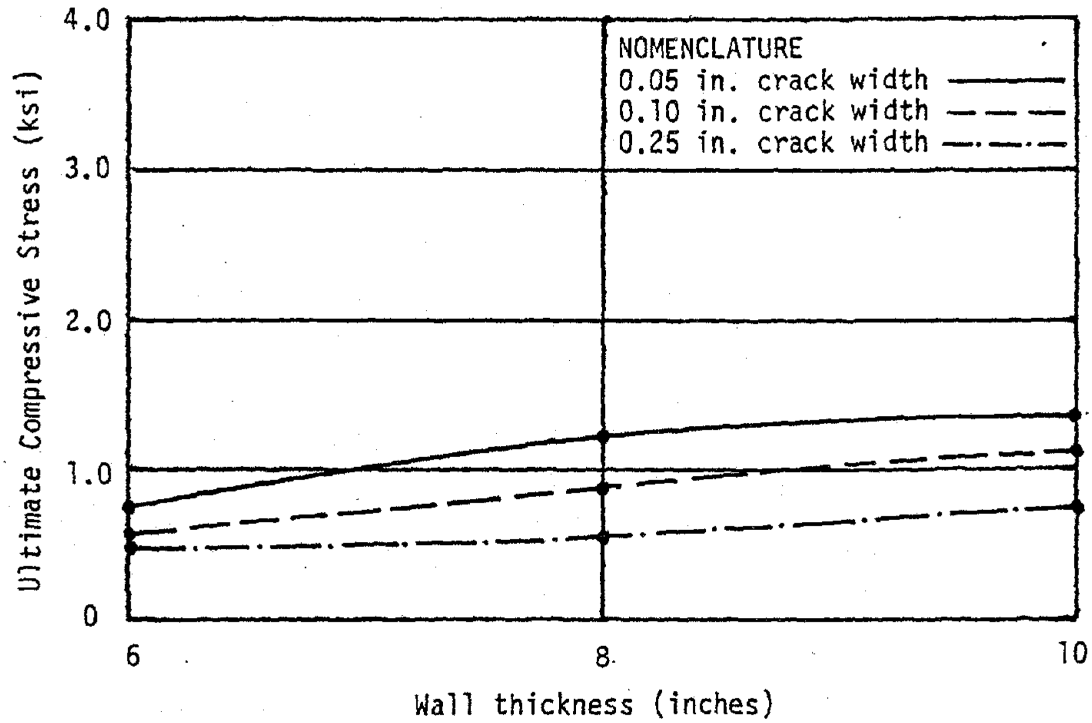

Fig. C-4a : Average Ultimate Compressive Stress as a Function of Wall Thickness

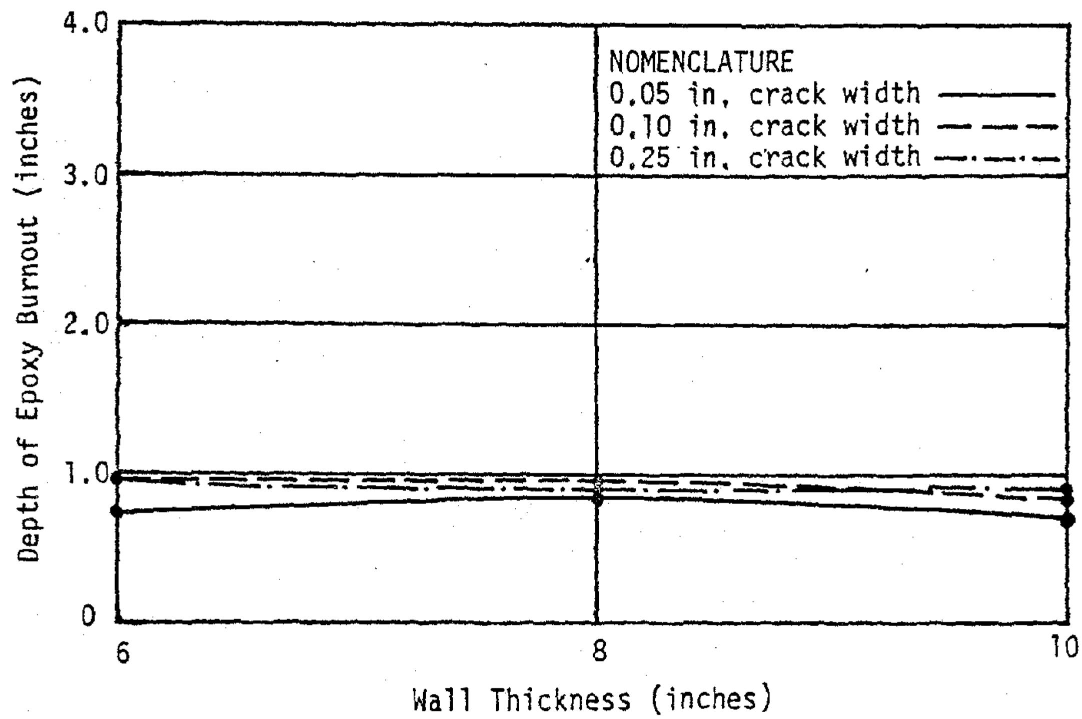

Fig. C-4b : Average Depth of Epoxy Burnout as a Function of Wall Thickness

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

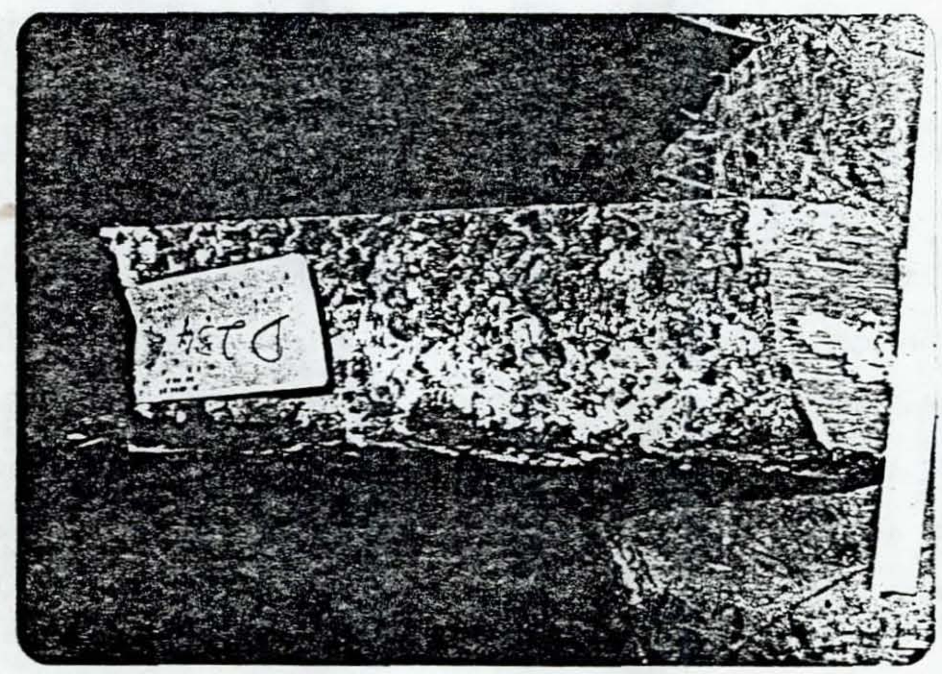

Fig. C-5a : Failure pattern for 6 in. Thick Specimen. Note the failure through the Epoxy.

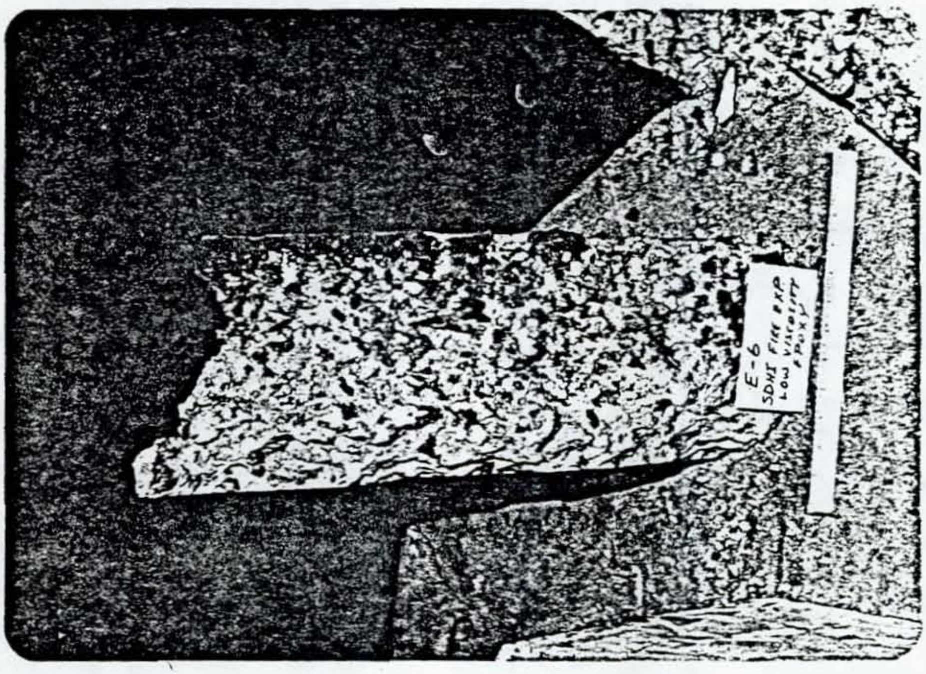

Fig. C-5b : Failure pattern for 8 in. Thick Specimen. Note the failure through the Concrete.

CHAPTER D: SMALL SCALE ASTM E119 RESIDUAL STRENGTH COMPRESSION TESTS (NO FIRE SURFACE COATING; LOW VISCOSITY EPOXY)

SEC. D.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in the Chapter D have been exposed to the standard 2-hour ASTM E119 fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in. and 0.25 in. and wall thicknesses of 6 in., 8 in., and 10 in. All specimens have been subjected to ultimate compression loads seven days after the 2-hour fire exposure.

SEC. D.2: SUMMARY OF TEST RESULTS

Tables D-1, D-2, and D-3 provide the test data for each specimen including the ultimate compression strength and the depth of epoxy burnout. Figs. D-1, D-2, and D-3 provide the graphical summary of average test results including average ultimate compressive stress and depth of epoxy burnout as a function of crack width. Fig. D-4 provides a complete summary of test results for average ultimate compressive stress and average depth of epoxy burnout as a function of wall thickness. Fig. D-5 provides a pictorial view of a typical failure pattern for specimens tested in this chapter. Ultimate compressive stress is a funciton of crack width due to the development of higher frictional forces between concrete surfaces in the case of smaller crack widths. Depth of epoxy burnout is not significantly affected by crack width. The failure pattern for the 6 in. thick wall specimens consisted of a combined shear failure in epoxy and concrete. For the 8 in. and 10 in. thick wall specimens, the failure pattern consisted usually of a shear failure in concrete.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Residual strength Compression test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: None

TABLE D-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.75	2.533	2.95	2.060	3.15	1.726
2	2.55	2.361	2.95	2.161	2.95	1.542
3	2.75	2.304	2.55	2.137	3.54	1.313
4						
Average	2.69	2.399	2.82	2.119	3.21	1.527
Standard Deviation	0.11	0.120	0.22	0.053	0.30	0.207

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page D-2 in TABLE D-1.

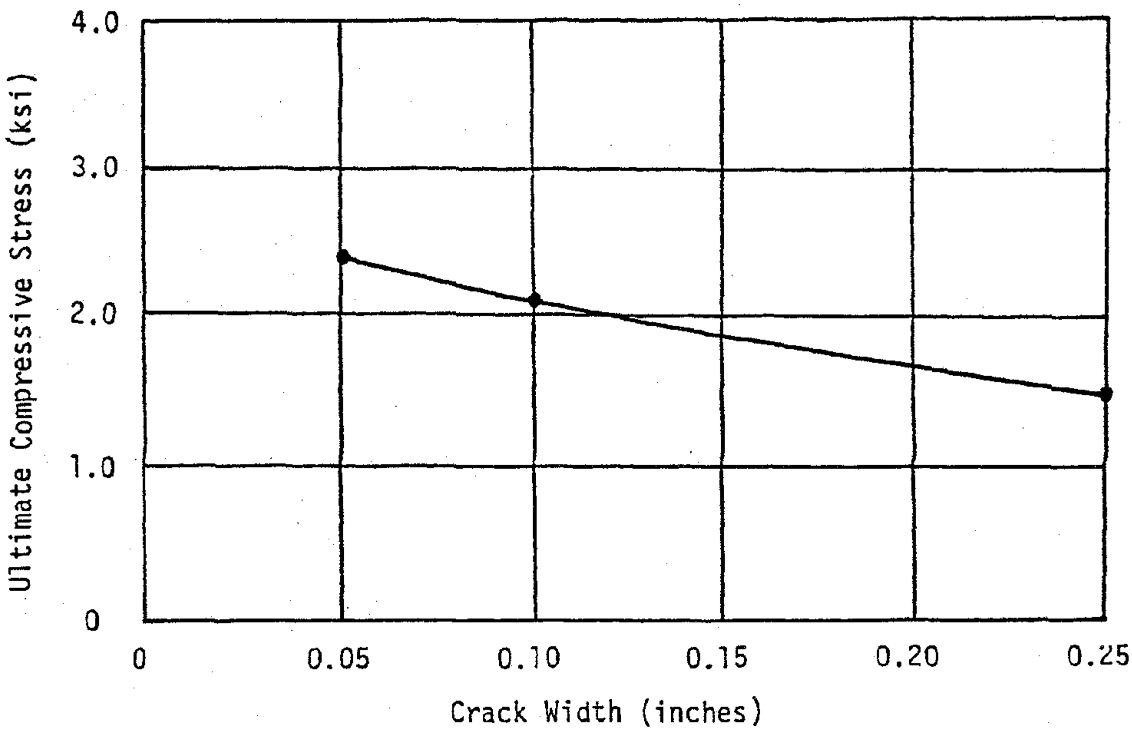

Fig. D-1a : Average Ultimate Compressive Stress as a Function of Crack Width

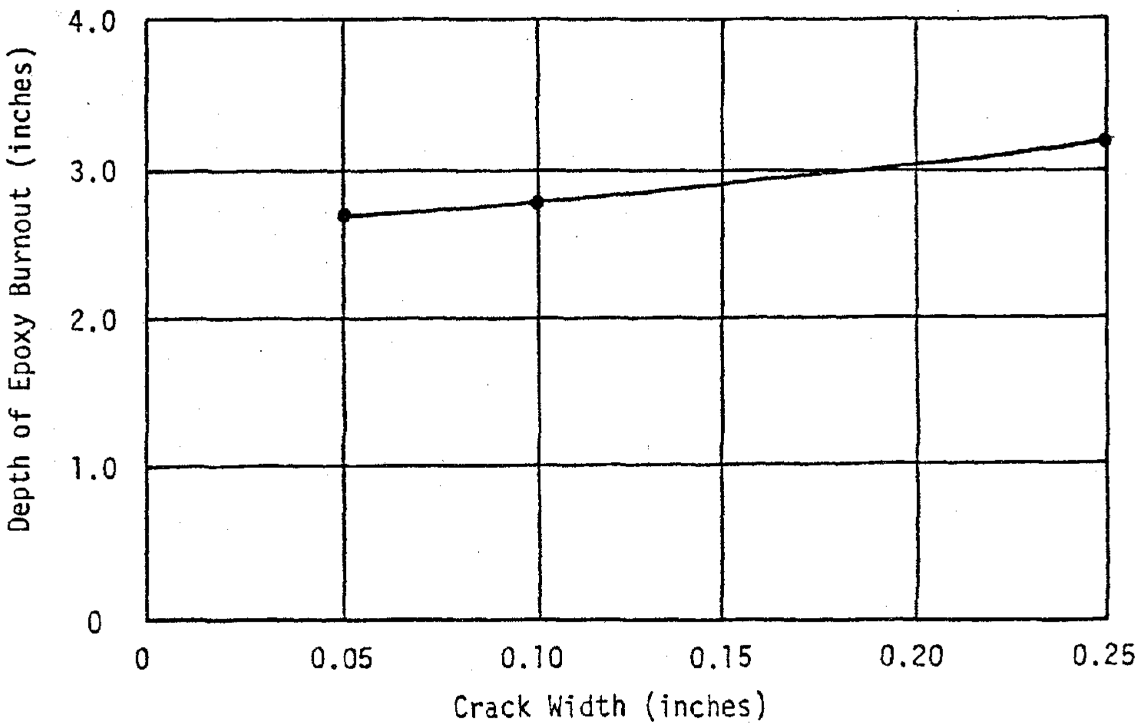

Fig. D-1b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 8 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Residual strength Compression test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: None

TABLE D-2

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress(ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.48	2.445	2.75	2.496	2.75	2.290
2	2.75	2.679	3.15	2.375	3.34	2.366
3	2.75	2.634	2.75	2.592	3.26	2.084
4						
Average	2.66	2.586	2.88	2.488	3.12	2.247
Standard Deviation	0.15	0.124	0.22	0.100	0.32	0.146

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page D-4 in TABLE D-2 .

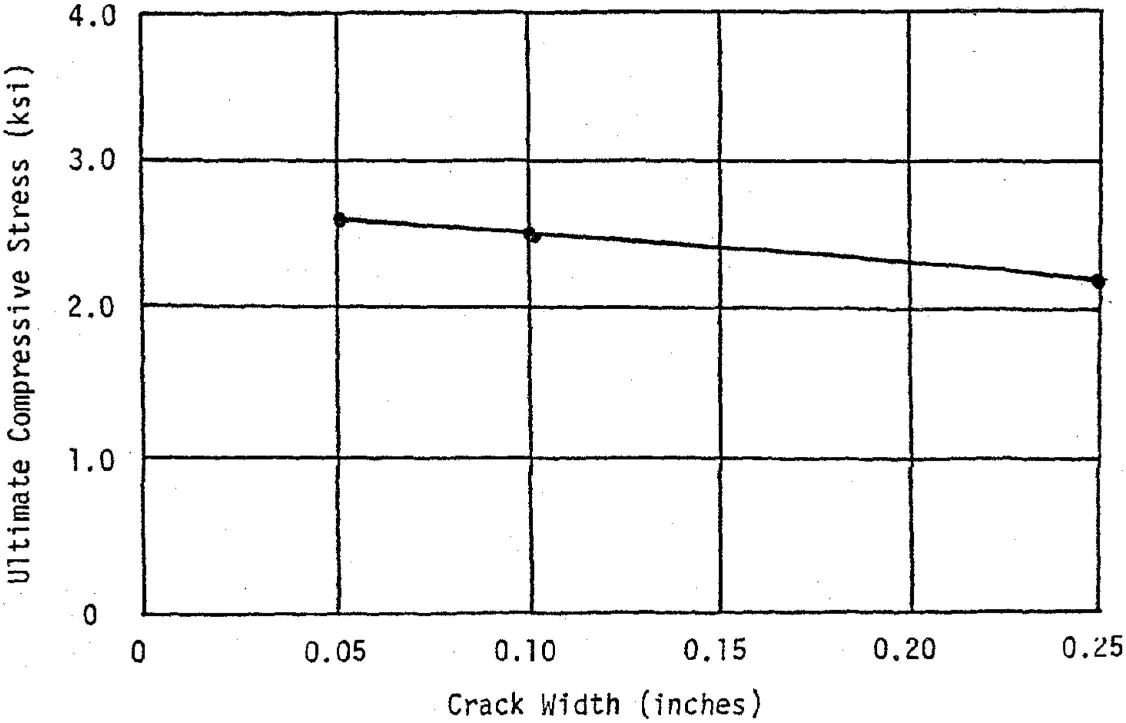

Fig. D-2a : Average Ultimate Compressive Stress as a Function of Crack Width

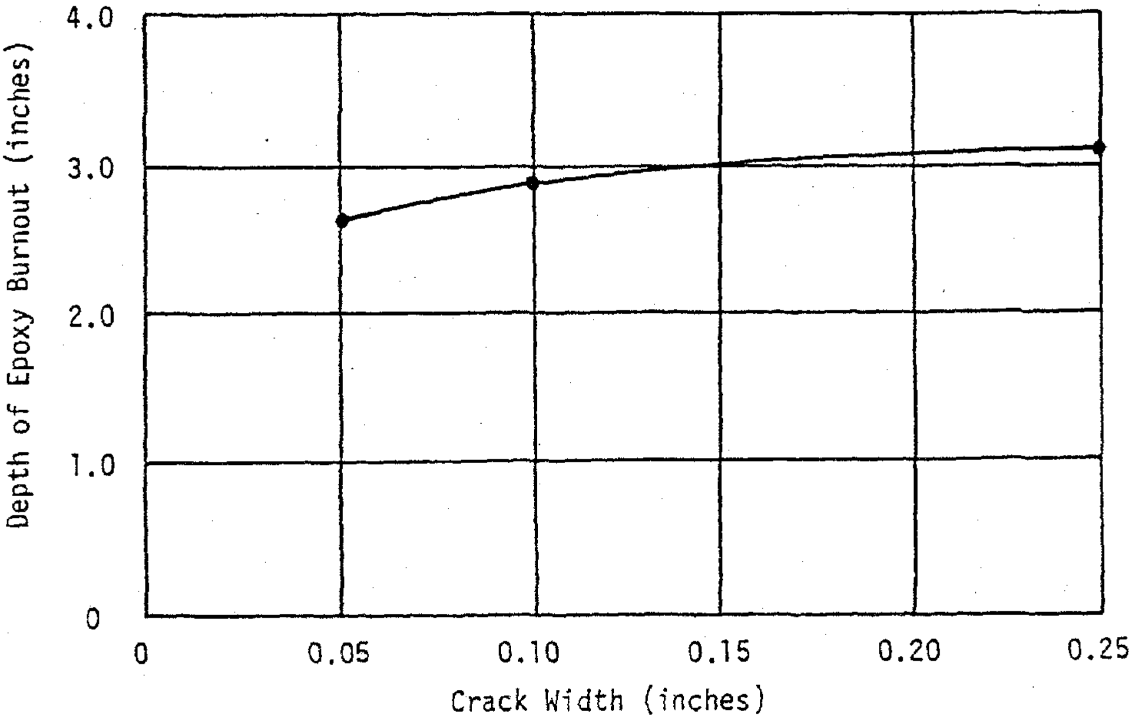

Fig. D-2b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 10 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Residual strength Compression test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: None

TABLE D-3

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.30	*	3.00	*	3.00	*
2	1.95	*	2.50	*	3.00	*
3	2.00	*	2.80	*	2.90	*
4						
Average	2.08		2.77		2.97	
Standard Deviation	0.19		0.25		0.06	

* The strength of this specimen was above the 300.00 Kips (2.14 Ksi) capacity of the experimental testing equipment.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

These graphs illustrate the average test results provided in TABLES D-1,D-2,D-3 as a function of specimen wall thickness for various crack widths.

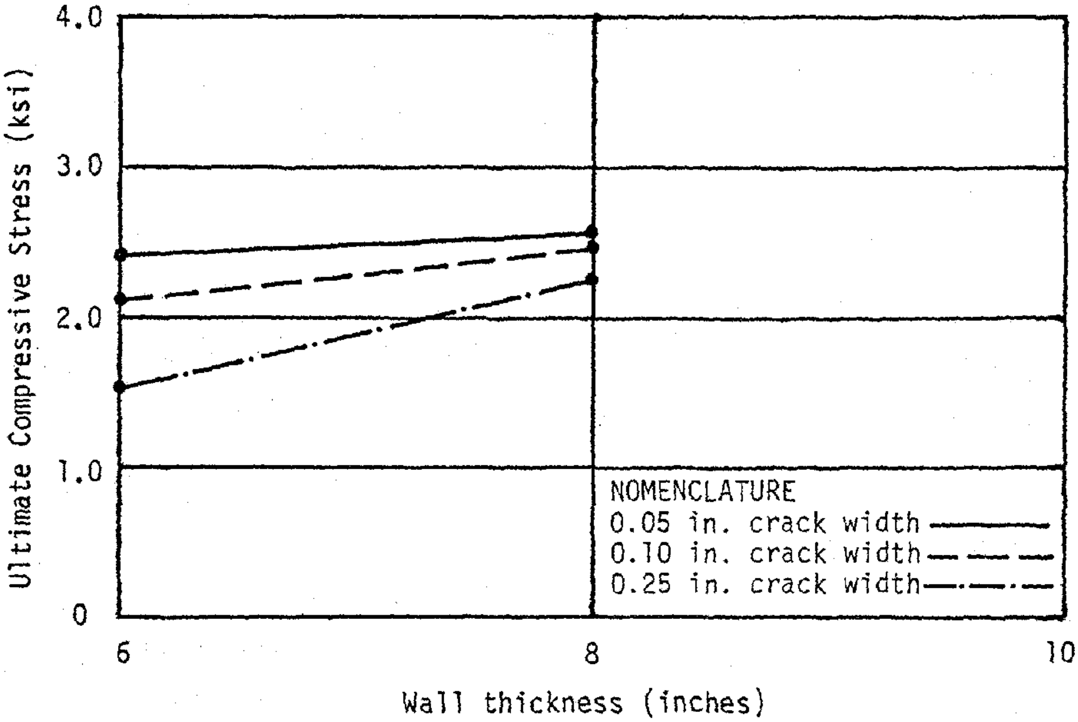

Fig. D-4a : Average Ultimate Compressive Stress as a Function of Wall Thickness

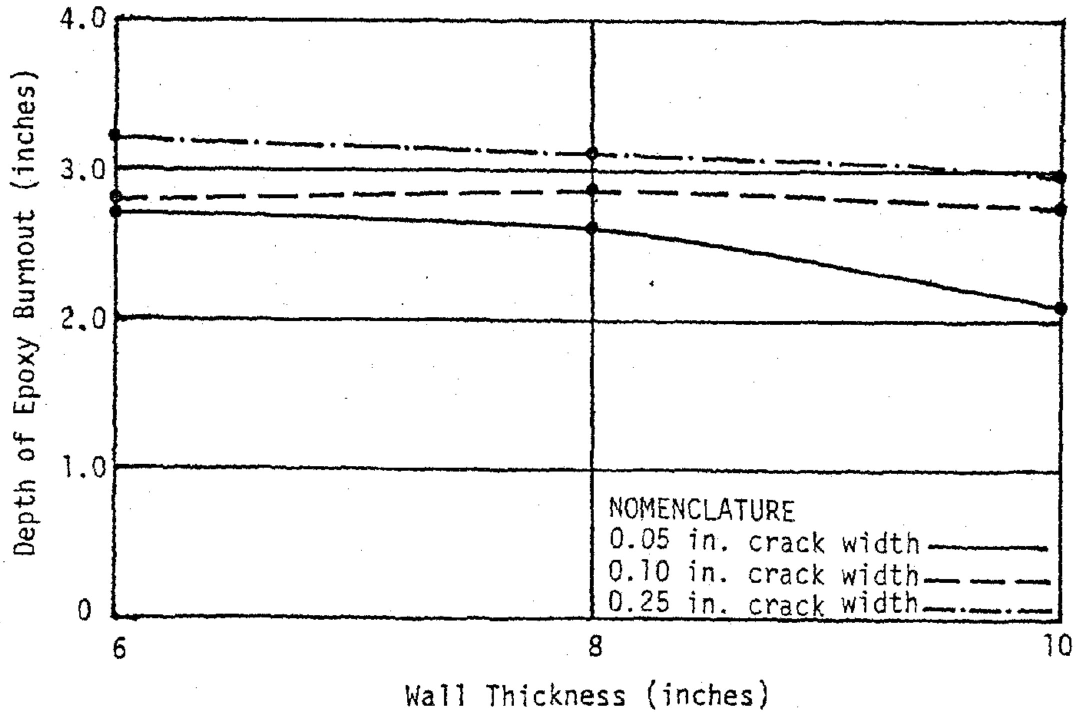

Fig. D-4b : Average Depth of Epoxy Burnout as a Function of Wall Thickness

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

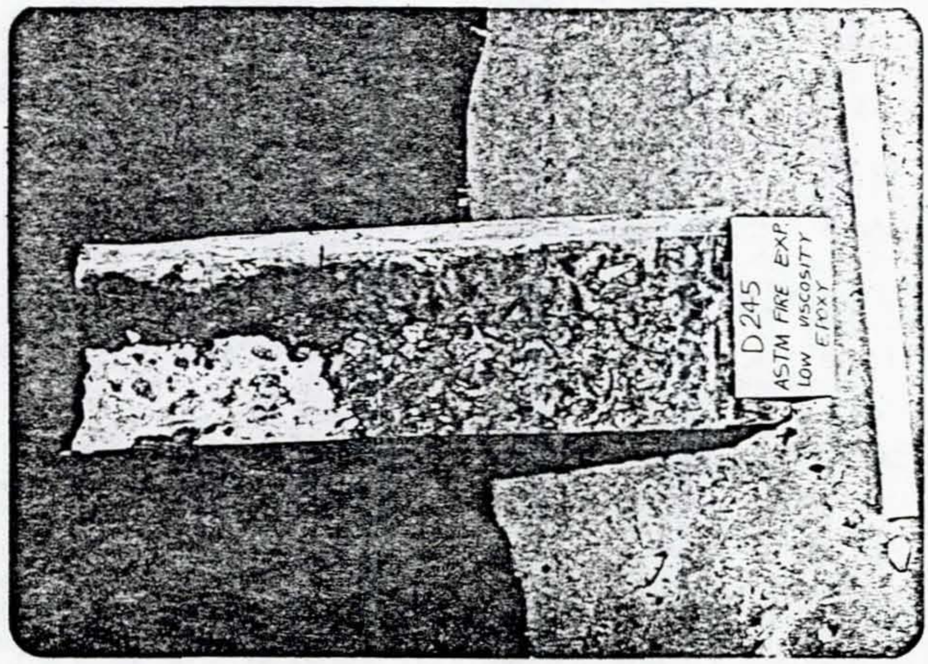

Fig. D-5a : Failure pattern for 6 in. Thick Specimen. Note the Combined Shear failure through Epoxy and Concrete

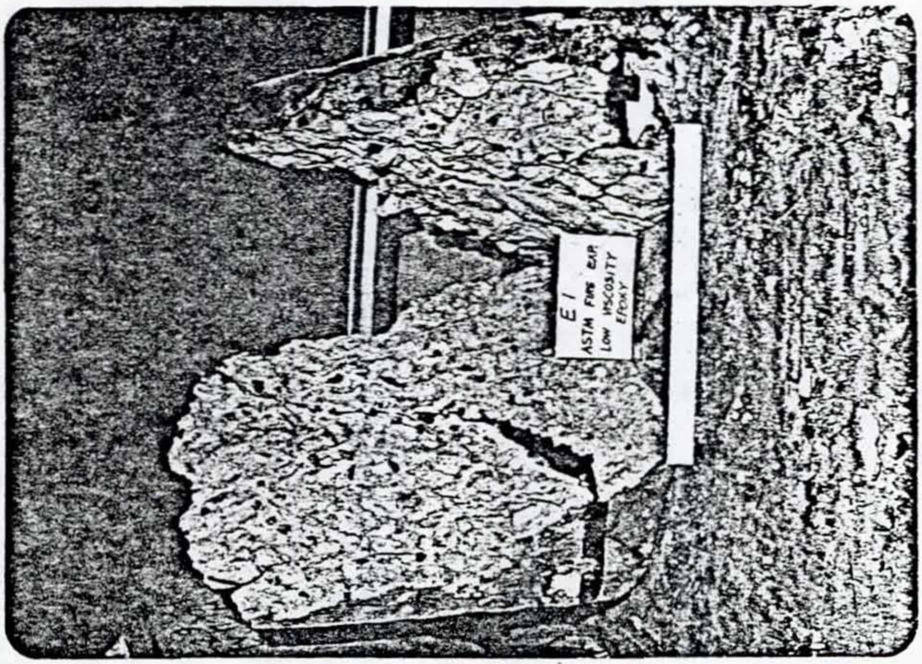

Fig. D-5b : Failure pattern for 8 in Thick Specimen. Note the Shear failure through Concrete not through Epoxy.

CHAPTER E: SMALL SCALE SDHI RESIDUAL STRENGTH COMPRESSION TESTS (NO FIRE SURFACE COATING; LOW VISCOSITY EPOXY)

SEC. E.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in this Chapter E have been exposed to the standard SDHI fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in. and 0.25 in. and wall thicknesses of 6 in., 8 in., and 10 in. All specimens have been subjected to ultimate compression loads seven days after the fire exposure.

SEC. E.2: SUMMARY OF TEST RESULTS

Tables E-1, E-2, and E-3 provide the test data for each specimen including the ultimate compression strength and the depth of epoxy burnout. Figs. E-1, E-2, and E-3 provide the graphical summary of average test results including average ultimate compressive stress and depth of epoxy burnout as a function of crack width. Fig. E-4 provides a complete summary of test results for average ultimate compressive stress and average depth of epoxy burnout as a function of wall thickness. Fig. E-5 provides a pictorial view of a typical failure pattern for specimens tested in this chapter. The failure pattern for all specimens, including 6 in., 8 in. and 10 in. shear wall specimens, consisted of shear failure in the concrete. Depth of epoxy burnout is not significantly affected by crack width.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Residual strength Compression test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE E-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress(ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0.78	3.452	0.98	3.256	0.98	3.343
2	0.78	*	0.78	3.571	0.98	2.452
3	0.70	*	0.78	2.690	0.98	2.780
4	0.78	3.548				
Average	0.76	3.536	0.85	3.173	0.98	2.858
Standard Deviation	0.03	0.057	0.11	0.446	0.00	0.450

* The strength of this specimen was above the 300.0 Kips (3.57 Ksi) capacity of the experimental testing equipment.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page E-2 in TABLE E-1 .

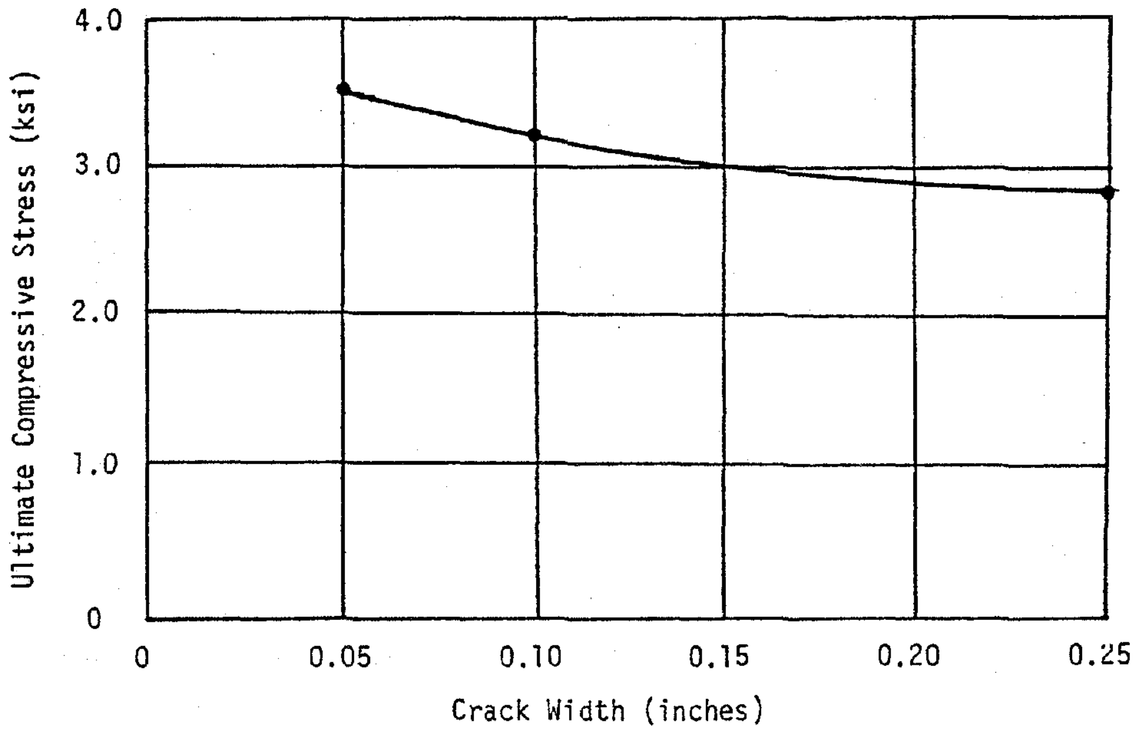

Fig. E-1a : Average Ultimate Compressive Stress as a Function of Crack Width

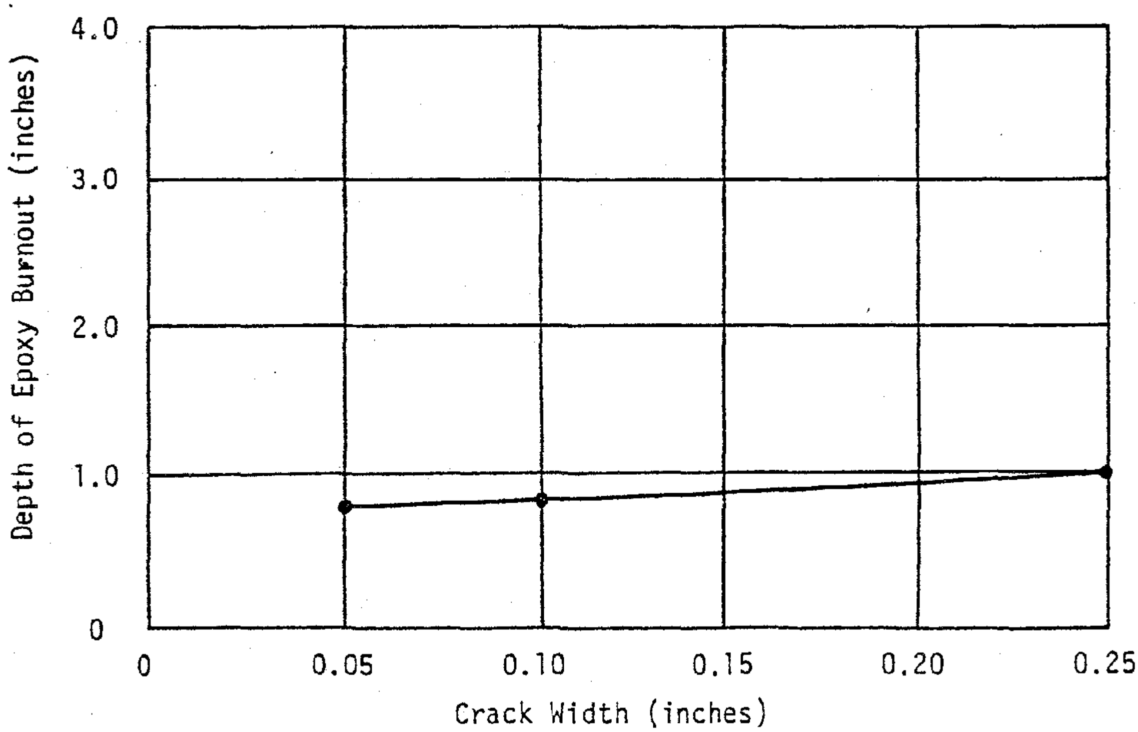

Fig. E-1b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 8 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Residual strength Compression test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE E-2

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0.78	*	1.18	*	0.98	*
2	0.78	*	0.98	*	1.10	2.634
3	1.06	*	0.78	*	0.78	*
4						
Average	0.87	*	0.98	*	0.95	*
Standard Deviation	0.15		0.19		0.15	

* The strength of this specimen was above the 300.00 Kips (2.68 Ksi) capacity of the experimental testing equipment.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page E-4 in TABLE E-2 .

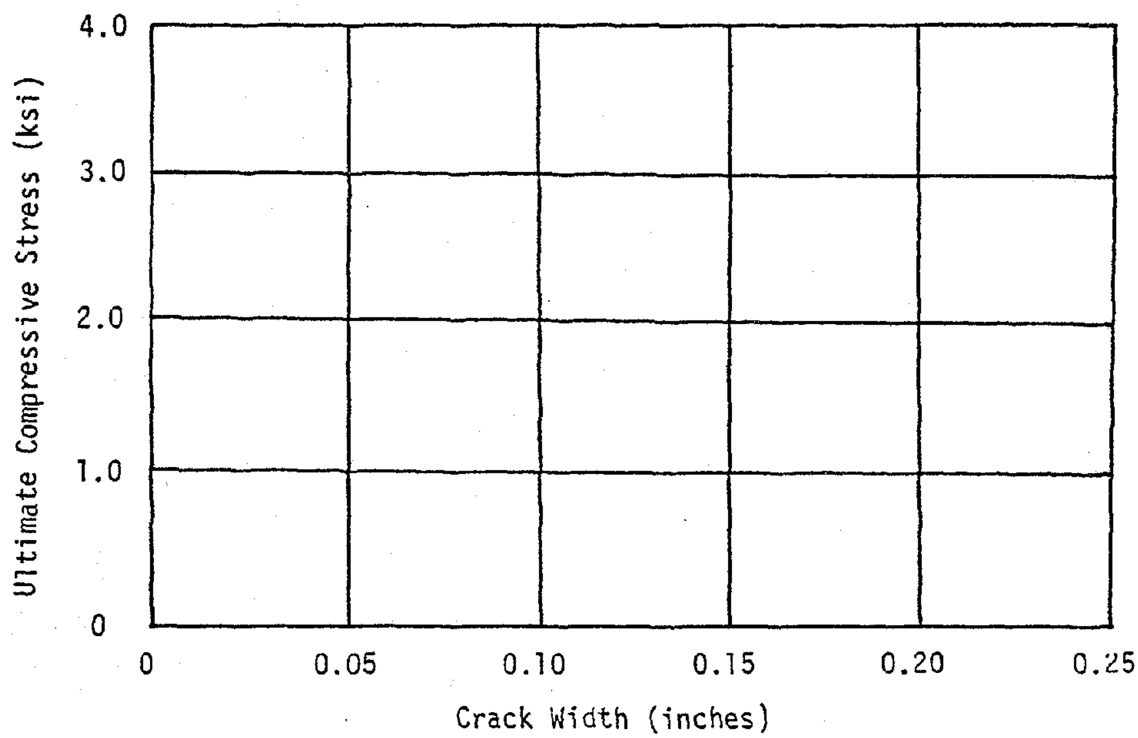

Fig.E-2a : Average Ultimate Compressive Stress as a Function of Crack Width

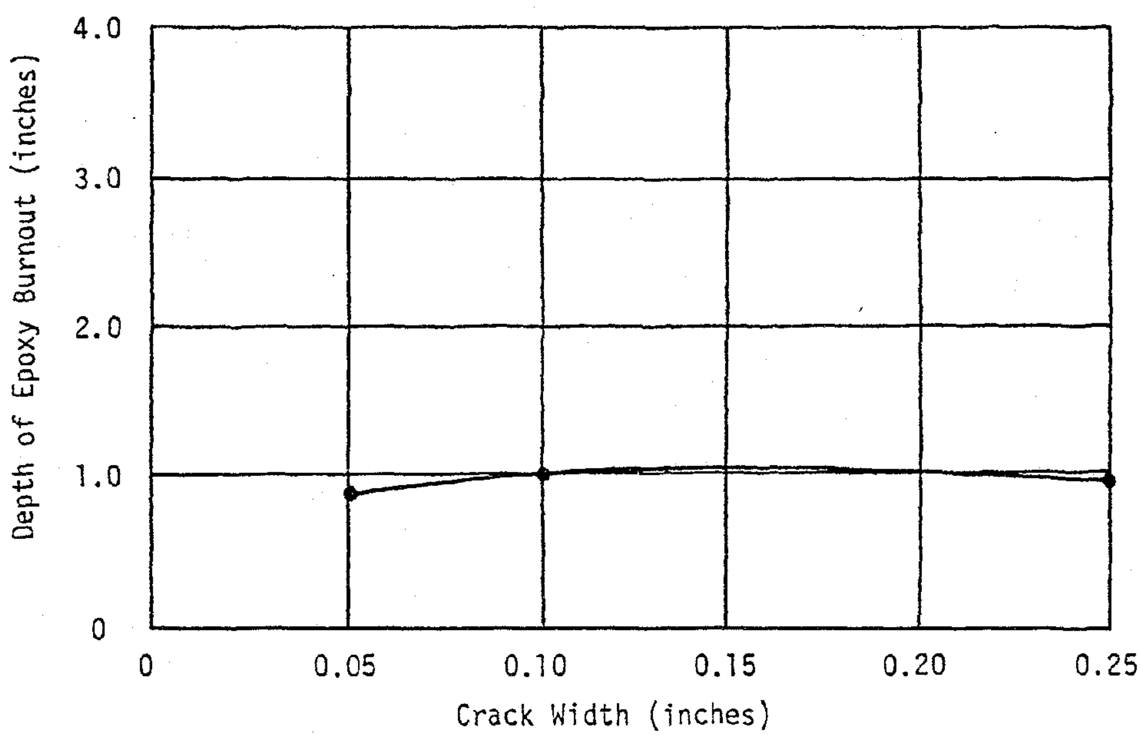

Fig.E-2b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 10 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Residual strength Compression test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE E-3

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0.78	*	0.78	*	0.98	*
2	0.78	*	0.98	*	0.98	*
3	0.78	*	0.98	*	0.98	*
4						
Average	0.78	*	0.91	*	0.98	*
Standard Deviation	0.00		0.11		0.00	

* The strength of this specimen was above the 300.00 Kips (2.14 Ksi) capacity of the experimental testing equipment.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page E-6 in TABLE E-3.

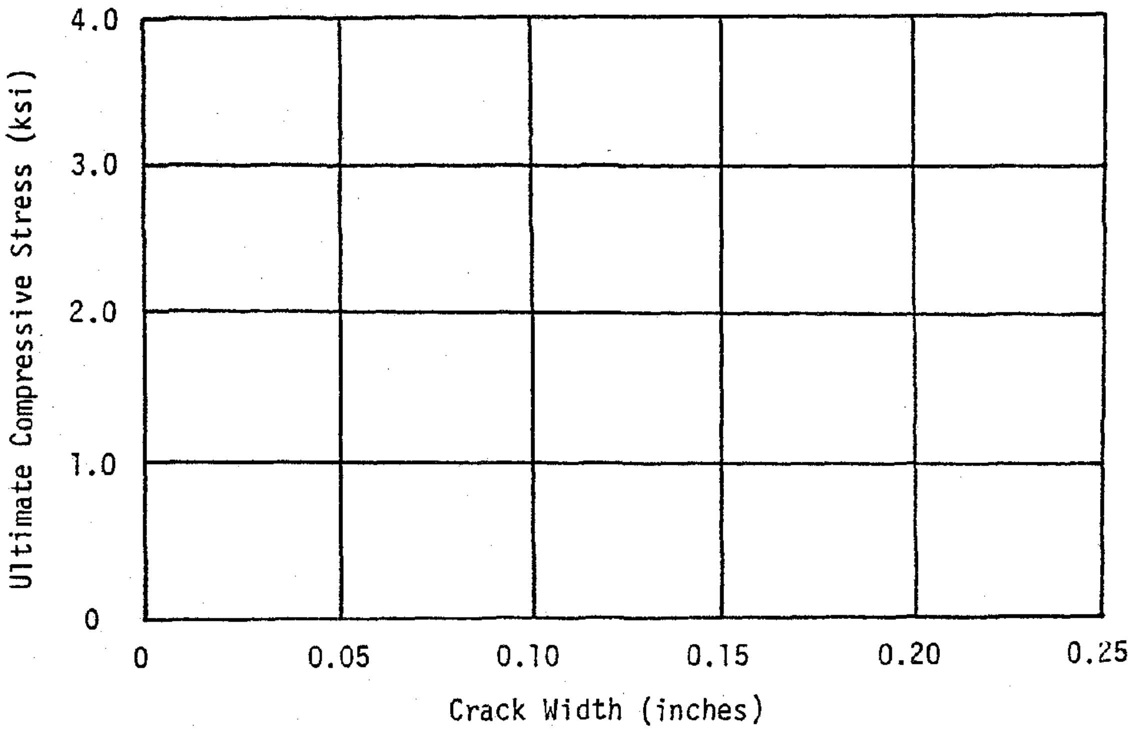

Fig.E-3a : Average Ultimate Compressive Stress as a Function of Crack Width

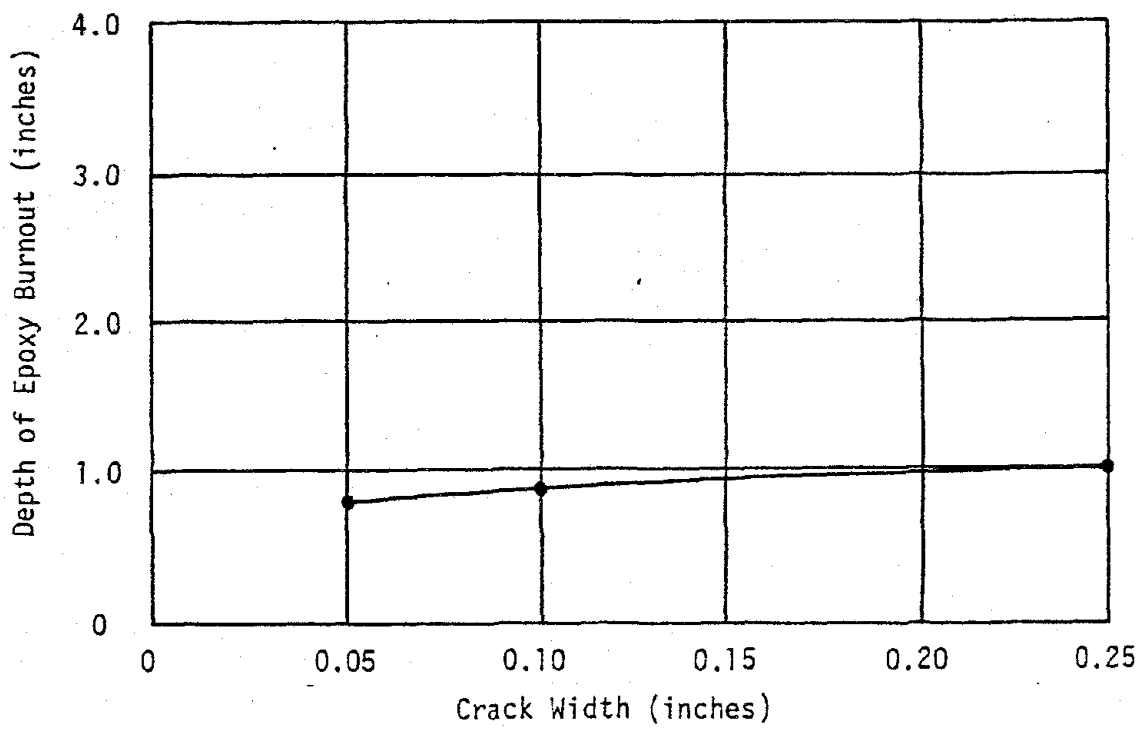

Fig.E-3b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

These graphs illustrate the average test results provided in TABLES E-1,E-2,E-3 as a function of specimen wall thickness for various crack widths.

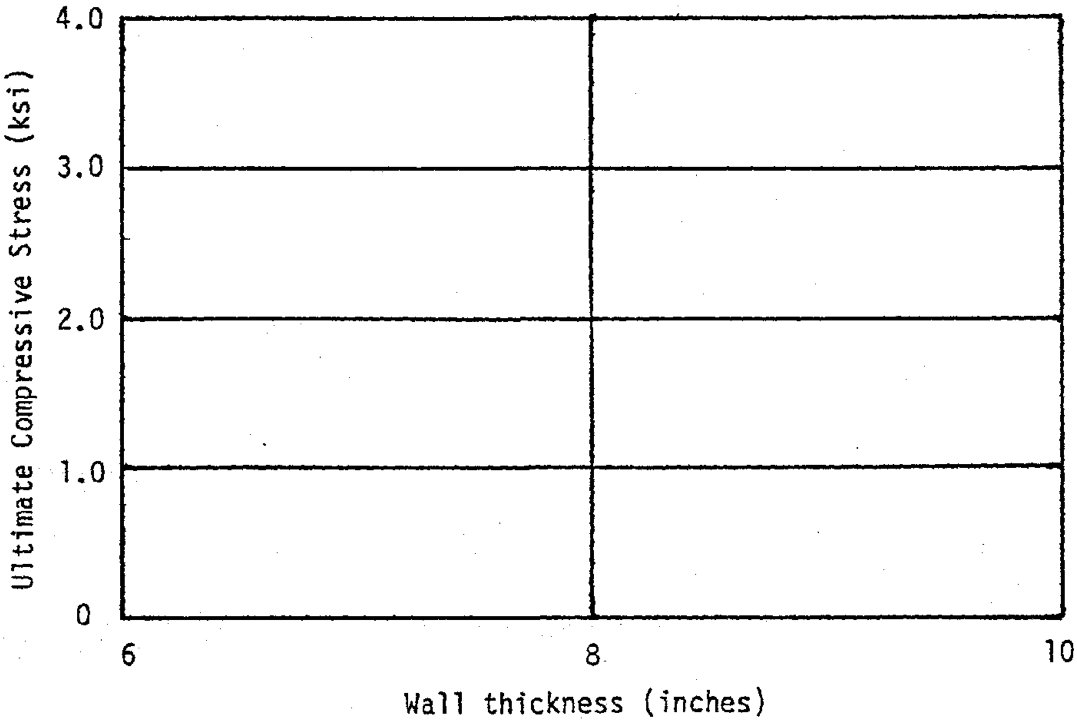

Fig. E-4a : Average Ultimate Compressive Stress as a Function of Wall Thickness

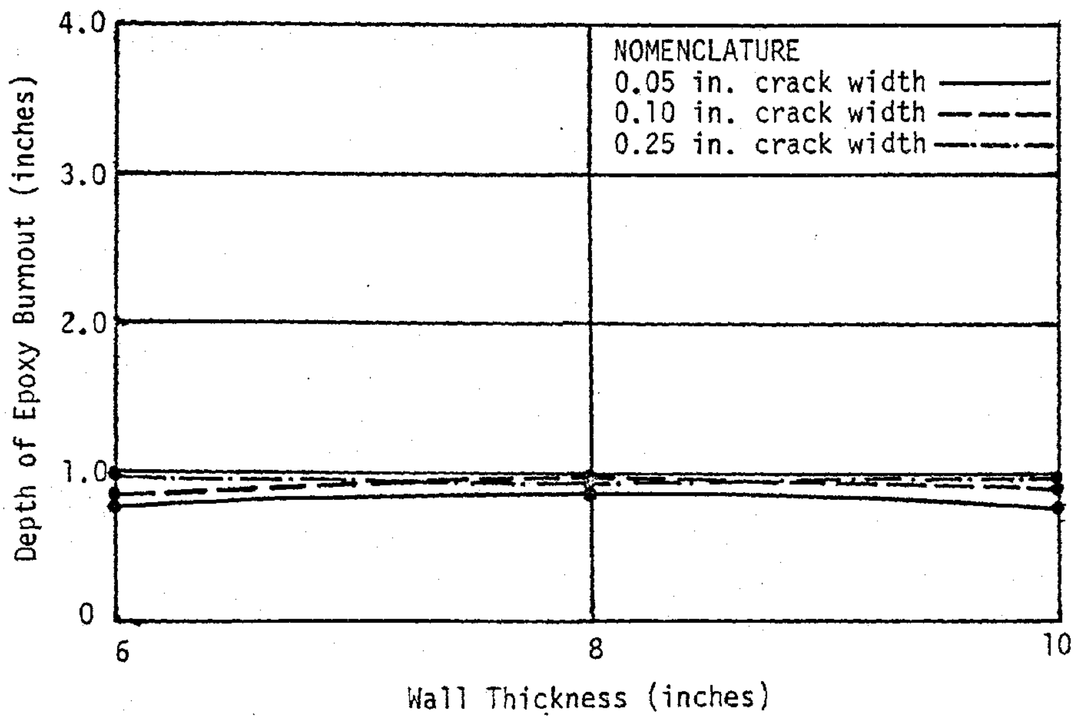

Fig. E-4b : Average Depth of Epoxy Burnout as a Function of Wall Thickness

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

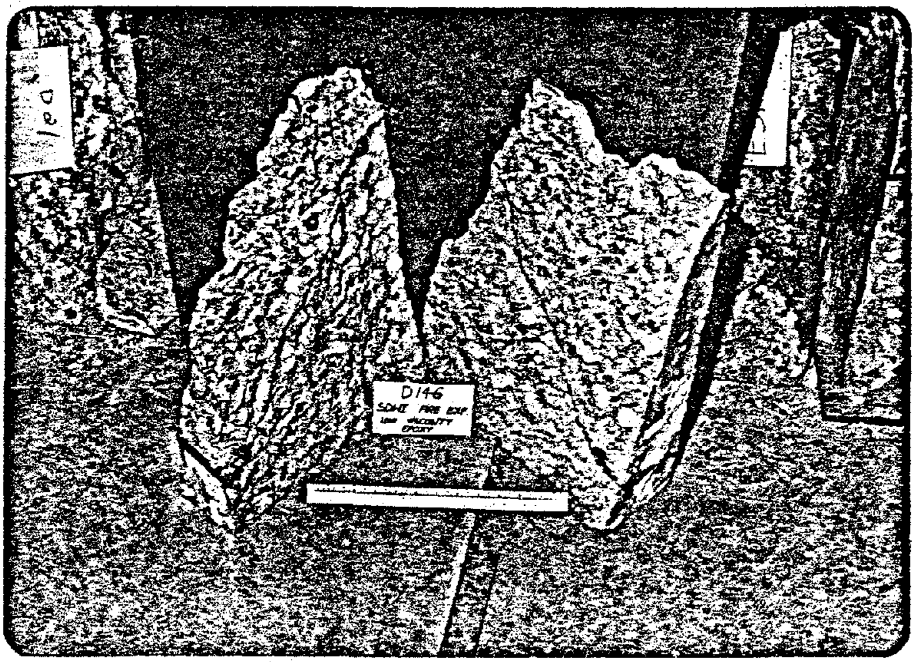

Fig. E-5 : Failure pattern for 6 in. Thick Specimen. Note the Shear failure through the Concrete.

CHAPTER F: SMALL SCALE ASTM E119 AND SDHI HOT STRENGTH COMPRESSION TESTS (NO FIRE SURFACE COATING; HIGH VISCOSITY EPOXY)

SEC. F.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of high viscosity type epoxies which have been described in Chapter A. Specimens considered in the Chapter F have been exposed to the standard 2-hour ASTM E119 or SDHI fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in. and 0.25 in. and wall thickness of 6 in. All specimens have been subjected to ultimate compression loads immediately after the fire exposure.

SEC. F.2: SUMMARY OF TEST RESULTS

Tables F-1 and F-2 provide the test data for each specimen including the ultimate compression strength and the depth of epoxy burnout. Figs. F-1 and F-2 provide the graphical summary of average test results including average ultimate compressive stress and depth of epoxy burnout as a function of crack width. Fig. F-3 provides a pictorial view of a typical failure pattern for specimens tested in this chapter. The failure pattern for all specimens, including both ASTM E119 and SDHI fire exposure specimens, consisted of shear failure in the epoxy since the temperatures within the specimens during the compression tests were above the heat distortion temperatures. Ultimate compressive stress is a function of crack width due to the development of higher frictional forces between concrete surfaces in the case of small crack widths. Depth of epoxy burnout is not significantly affected by crack width. Comparison with results in Chapters B and C indicates that the low and high viscosity epoxies considered in this research program provide very similar results.

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: High Viscosity (15,000 cps); Structural Grade Epoxy

LOAD CONDITIONS: Hot Strength Compression Test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: None

TABLE F-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.75	0.601	2.55	0.575	2.75	0.060
2	2.55	0.858	2.75	0.610	2.75	0.060
3	2.55	0.798	2.75	0.442	2.95	0.060
4						
Average	2.62	0.752	2.69	0.542	2.82	0.060
Standard Deviation	0.11	0.134	0.11	0.090	0.11	0.000

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page F-2 in TABLE F-1 .

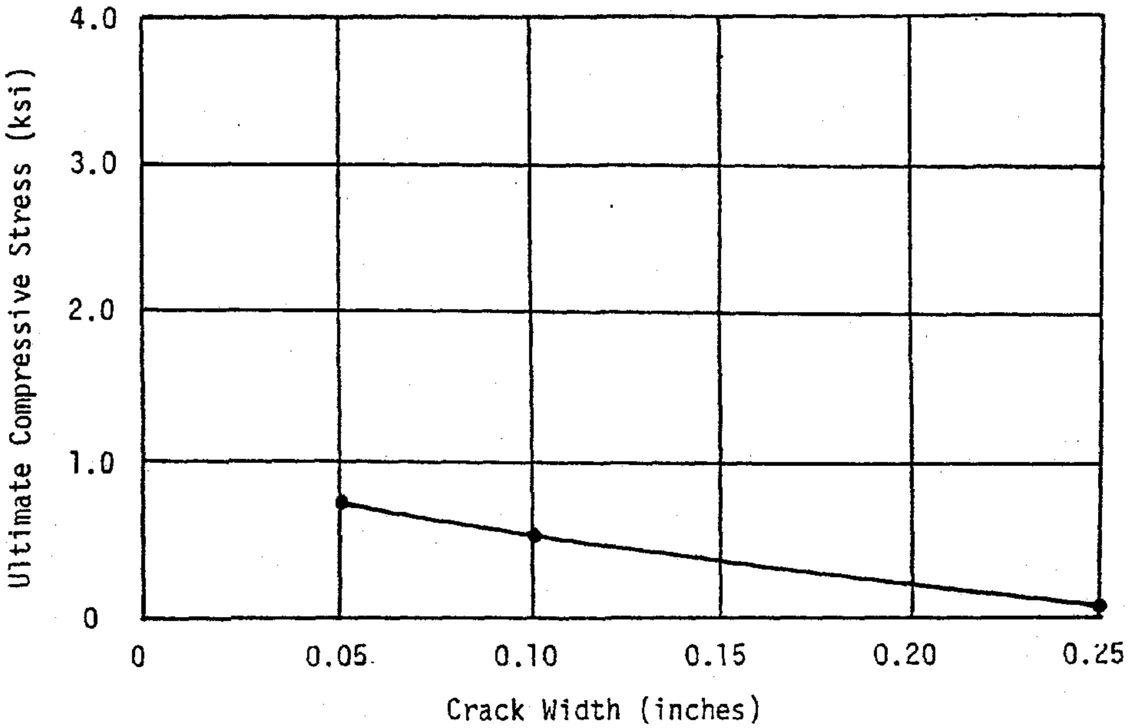

Fig.F-1a : Average Ultimate Compressive Stress as a Function of Crack Width

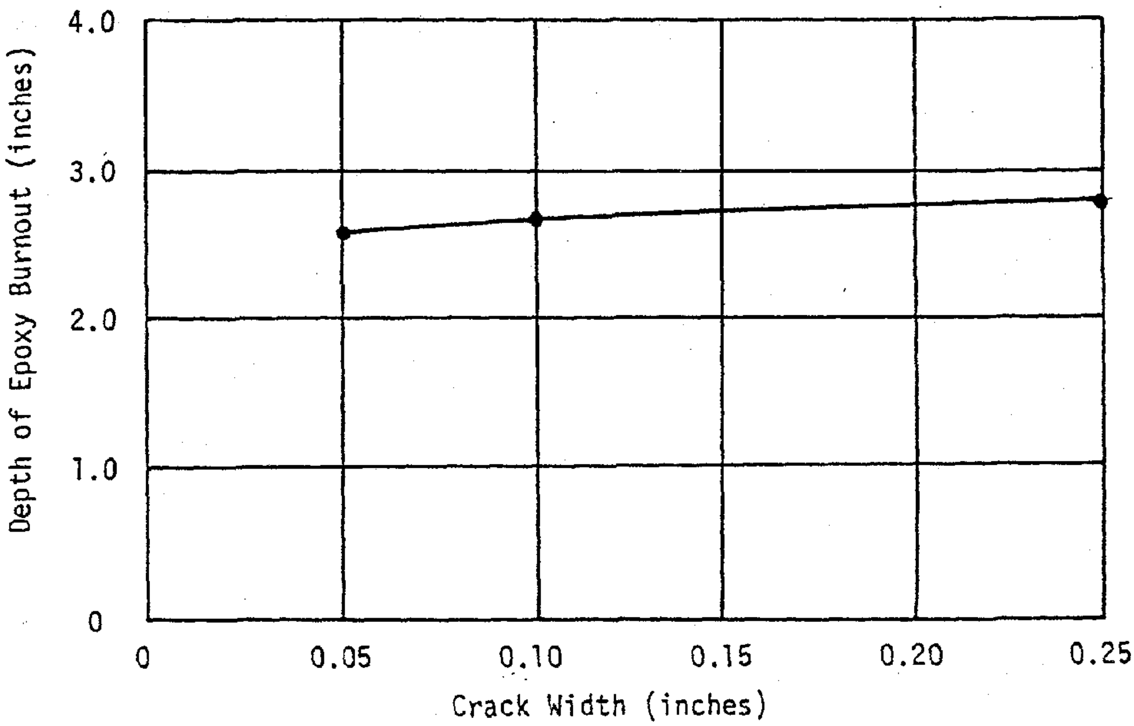

Fig.F-1b : Average Depth of Epoxy Burnout as a Function of Crack Width

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: High Viscosity (15,000 cps); Structural Grade Epoxy

LOAD CONDITIONS: Hot Strength Compression Test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE F-2

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi
1	0.78	0.718	0.78	0.574	1.02	0.417
2	0.70	0.894	0.78	0.893	0.78	0.514
3	0.70	0.952	0.78	0.620	0.90	0.585
4						
Average	0.73	0.855	0.78	0.696	0.90	0.505
Standard Deviation	0.04	0.122	0.00	0.172	0.11	0.084

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page F-4 in TABLE F-2 .

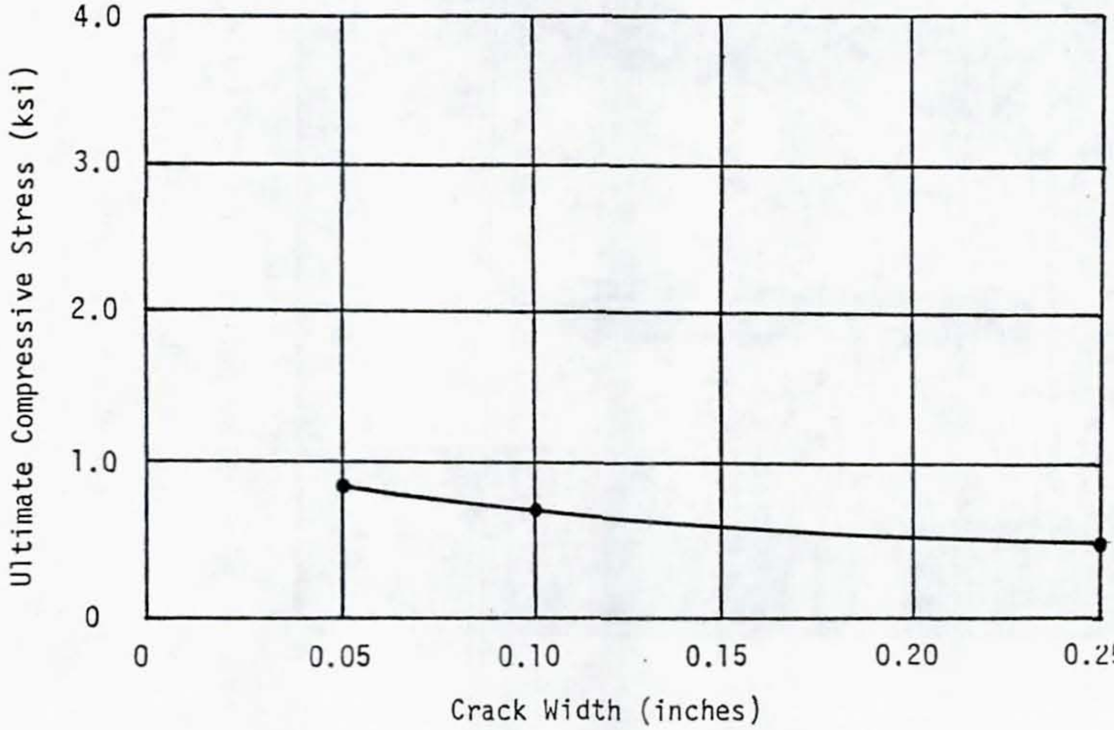

Fig. F-2a : Average Ultimate Compressive Stress as a Function of Crack Width

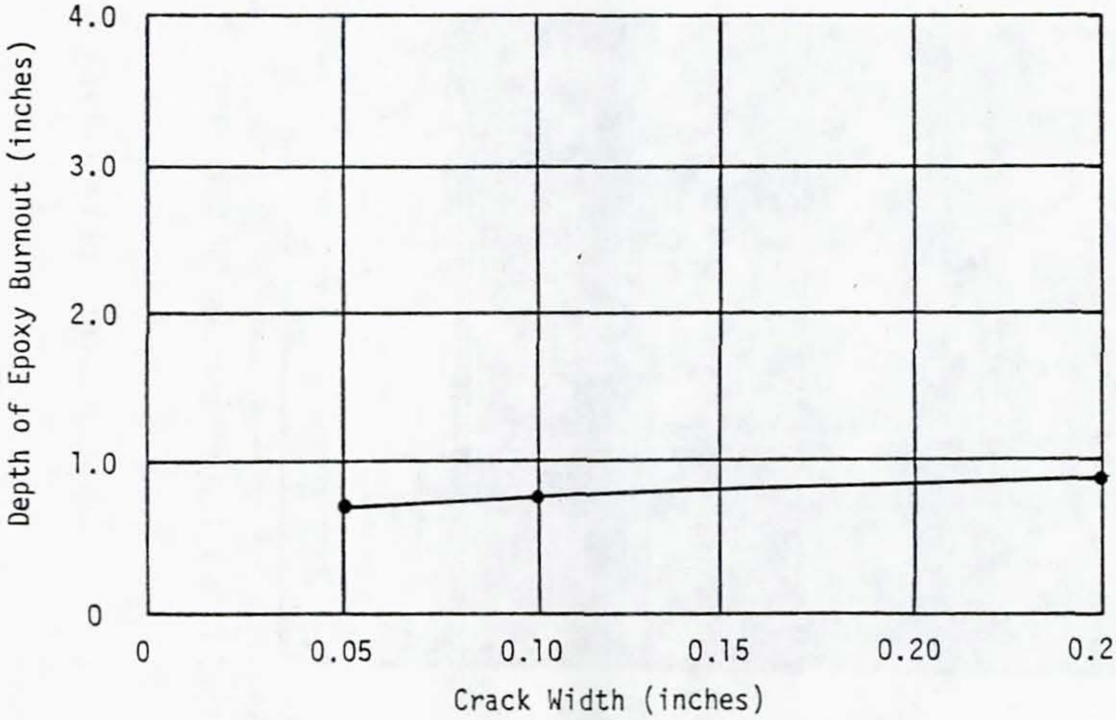

Fig.F-2b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

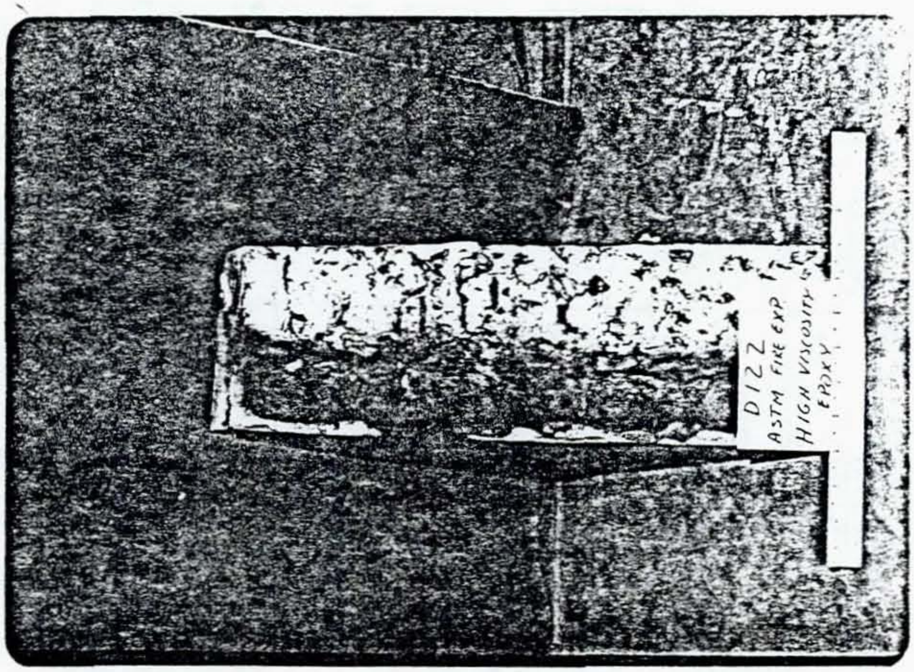

Fig. F-3a : Failure pattern for 6 in. Thick Specimen, High Viscosity Epoxy and ASTM E-119 Fire Exposure.

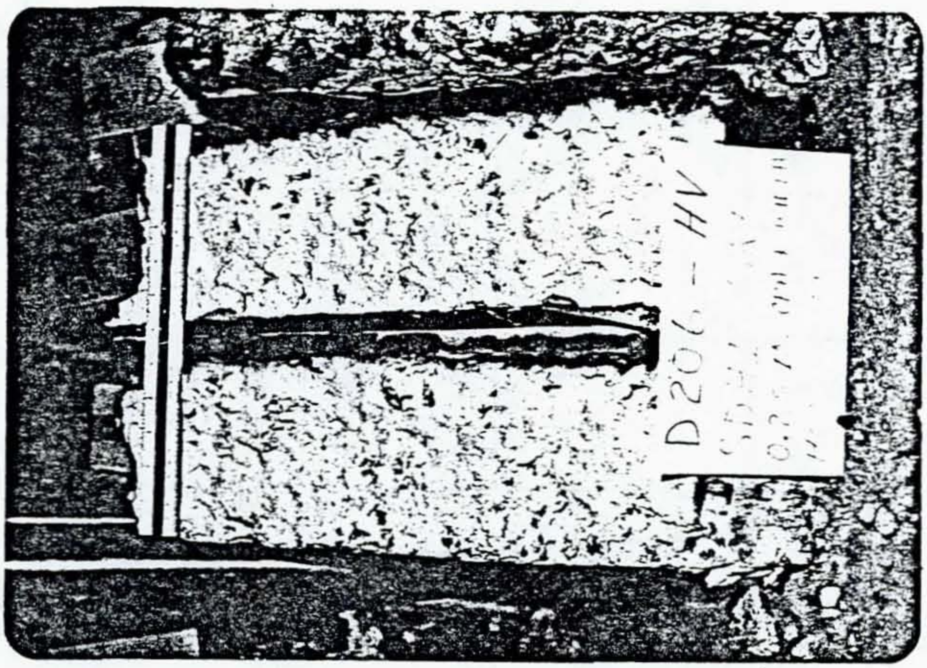

Fig. F-3b : Failure pattern for 6 in. Thick Specimen, High Viscosity Epoxy and SDHI Fire Exposure.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

CHAPTER G: SMALL SCALE ASTM E119 HOT STRENGTH COMPRESSION TESTS (PLASTER FIRE SURFACE COATING: LOW VISCOSITY EPOXY)

SEC. G.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in this Chapter G have been exposed to the standard 2-hour ASTM E119 fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in., and 0.25 in., wall thickness of 6 in., and plaster coating on fire exposed surface of 1 in. and 3/8 in. thickness. The plaster was applied to the specimens as described in Chapter A. All specimens have been subjected to the ultimate compression loads immediately after the 2-hour fire exposure.

SEC. G.2: SUMMARY OF TEST RESULTS

Table G-1 provides the test data and Fig. G-1 provides the corresponding graphical summary for specimens that have had a 1 in. plaster coating applied to the fire exposed surface. Table G-2 provides the test data and Fig. G-2 provides the corresponding graphical summary for specimens that have had a 3/8 in. plaster coating applied to the fire exposed surface. Fig. G-5 provides a pictorial view of the epoxy burnout and failure pattern. Comparison of results in this Chapter with corresponding unplastered test results in Chapter B indicates that 1 in. thick plaster coating is extremely effective in reducing depth of epoxy burnout but is not effective in increasing ultimate "hot" stress as illustrated in Fig. G-3. The lower effectiveness of 3/8 in. thick plaster coating is also illustrated in Fig. G-4. The effectiveness of both the 1 in. and the 3/8 in. thick plaster coatings in reducing the depth of epoxy burnout indicates that "residual strengths" are increased substantially by the application of both the 1 in. and the 3/8 in. thick plaster coatings.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot Strength Compression Test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: 1 inch Plaster Coating

TABLE G-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0.78	0.489	0.78	0.387	0.78	0.244
2	0.70	0.423	0.78	0.489	0.78	0.351
3	0.70	0.762	0.39	0.590	0.78	0.244
4	0.59	0.798				
Average	0.69	0.618	0.65	0.489	0.78	0.280
Standard Deviation	0.08	0.190	0.22	0.102	0.00	0.062

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page G-2 in TABLE G-1 .

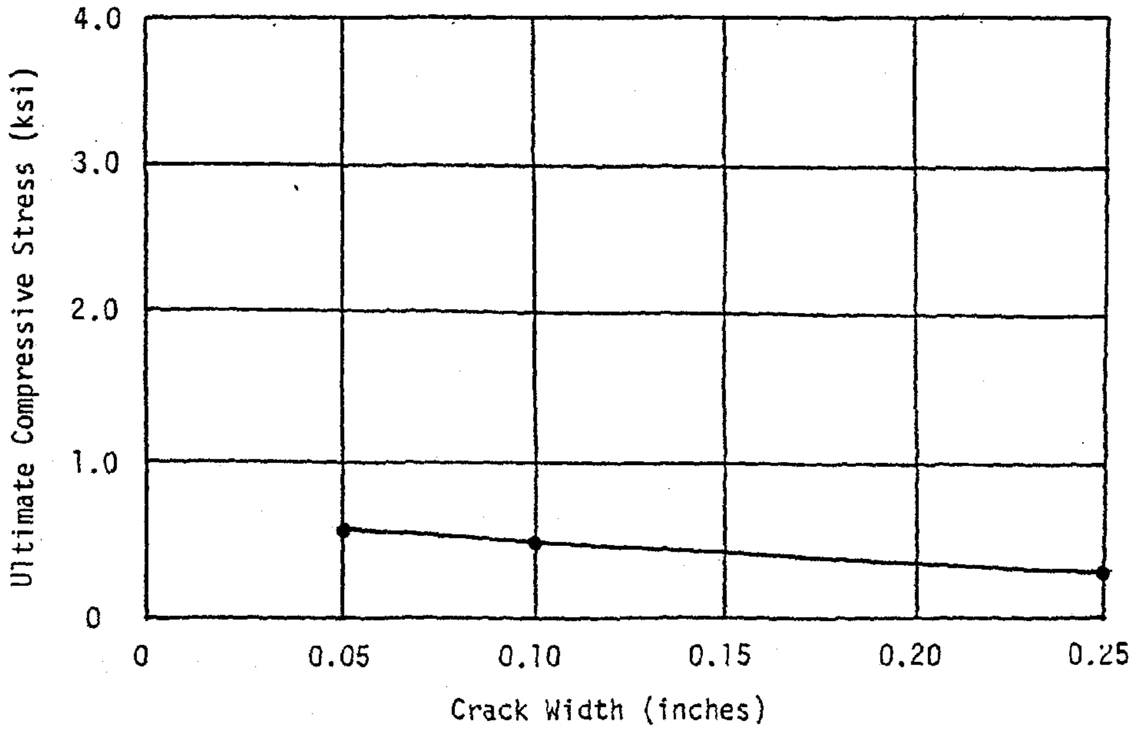

Fig.G-1a : Average Ultimate Compressive Stress as a Function of Crack Width

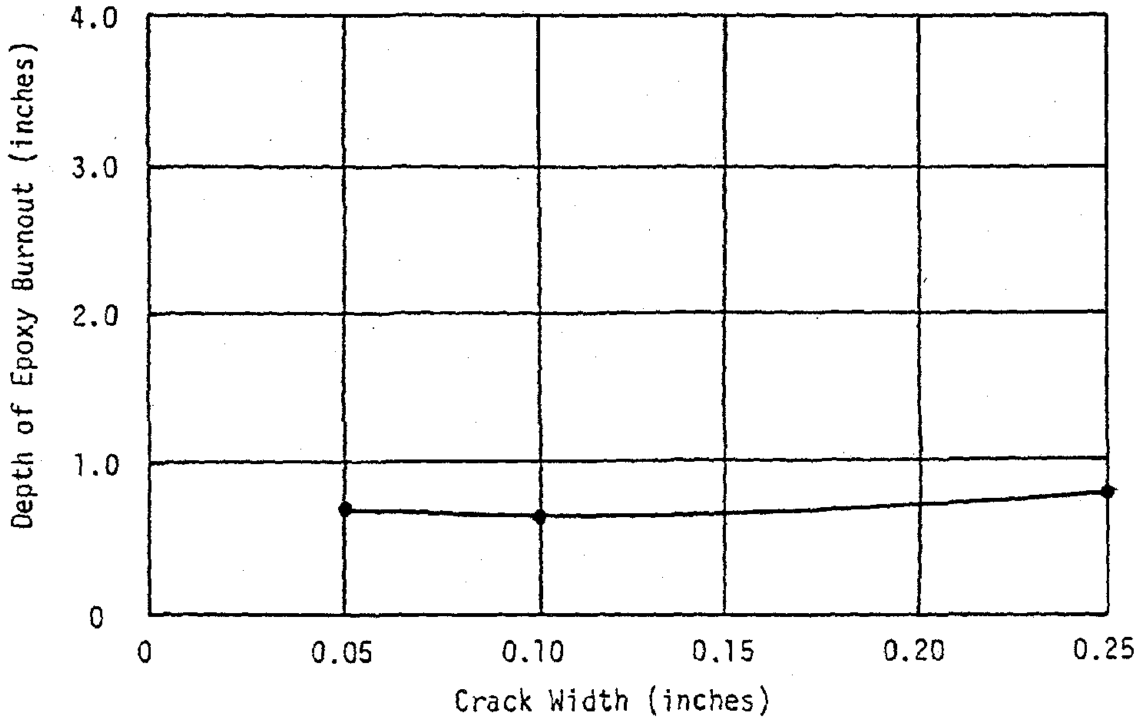

Fig.G-1b : Average Depth of Epoxy Burnout as a Function of Crack Width

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot Strength Compression Test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: 3/8 inch Plaster Coating

TABLE G-2

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	1.77	0.507	1.57	0.439	1.96	0.146
2	1.57	0.762	2.16	0.455	1.18	0.146
3	1.37	0.619	1.81	0.524	1.57	0.119
4						
Average	1.57	0.629	1.85	0.473	1.57	0.137
Standard Deviation	0.19	0.128	0.29	0.045	0.39	0.016

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page G-4 in TABLE G-2 .

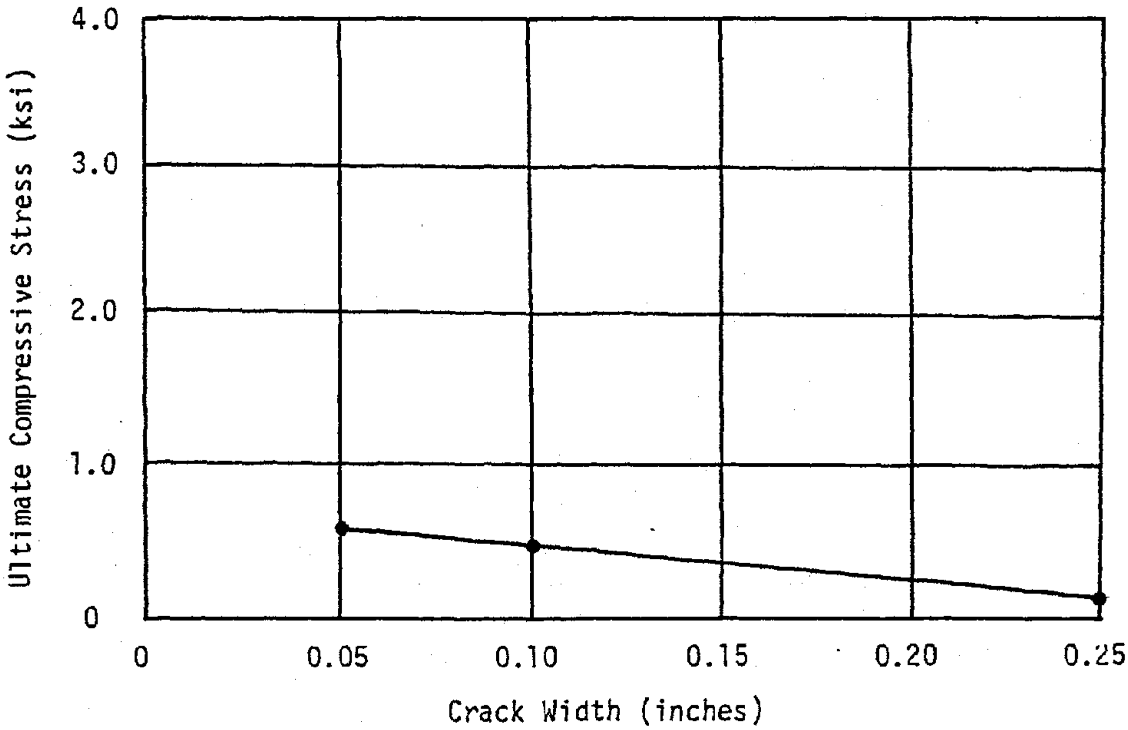

Fig.G-2a : Average Ultimate Compressive Stress as a Function of Crack Width

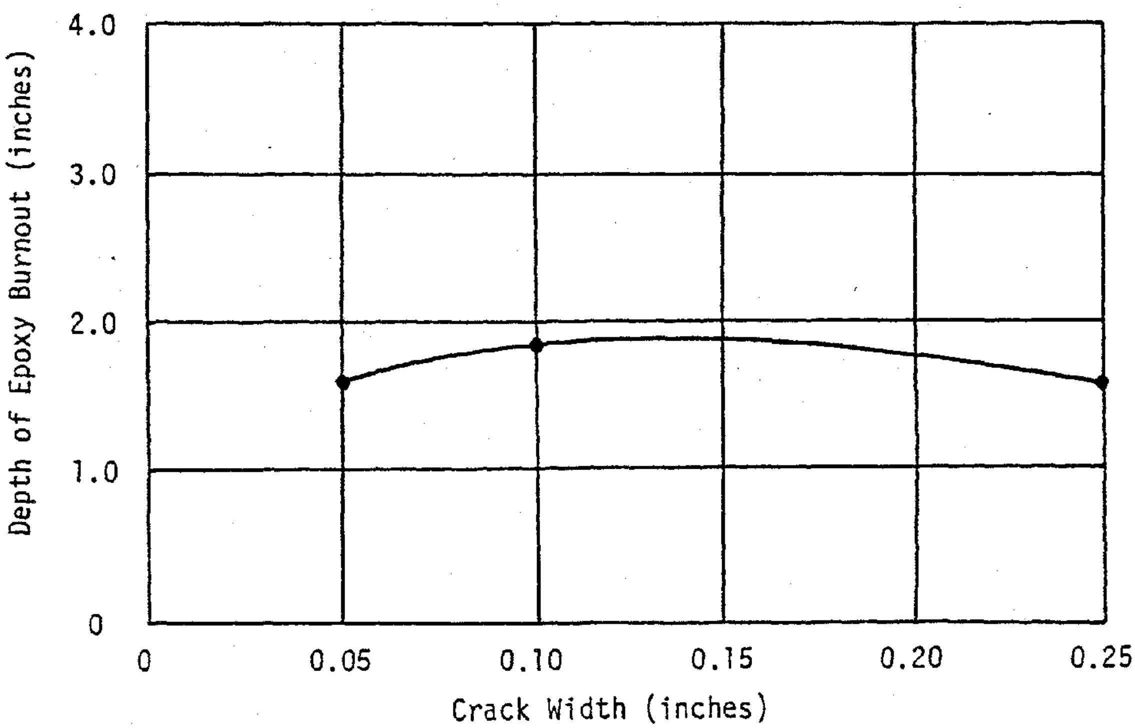

Fig.G-2b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page B-2,G-2 in TABLE B-1,G-1

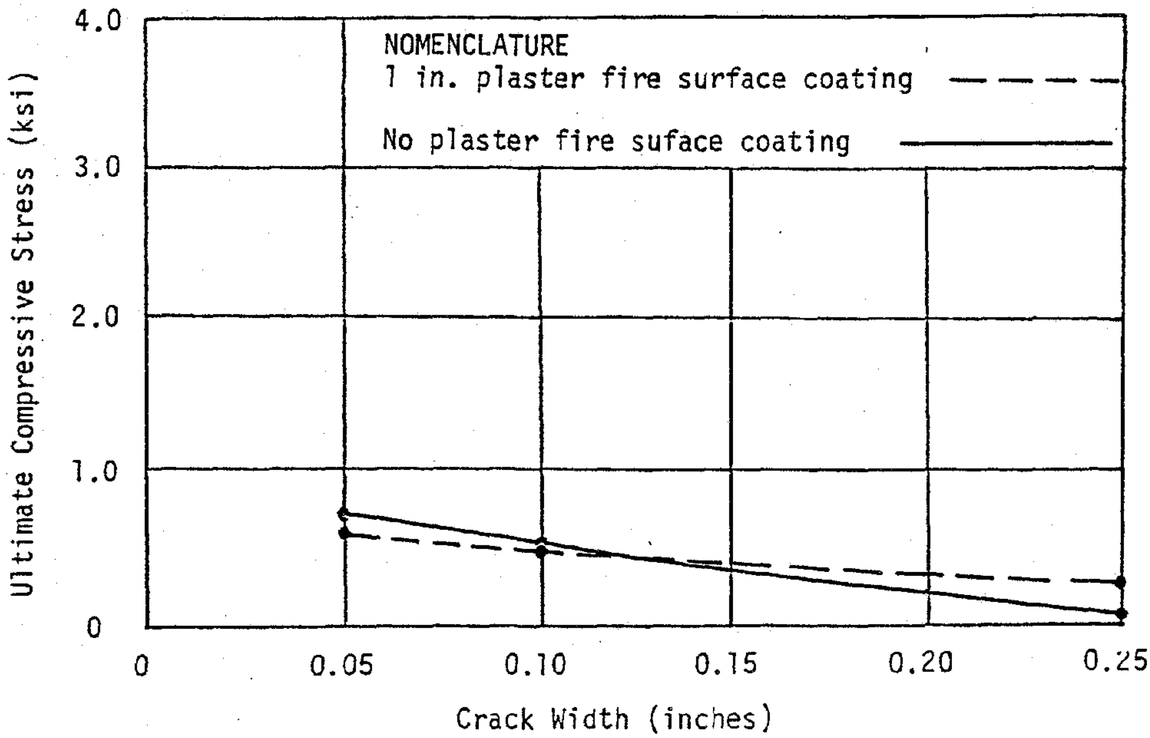

Fig. G-3a: Average Ultimate Compressive Stress as a Function of Crack Width

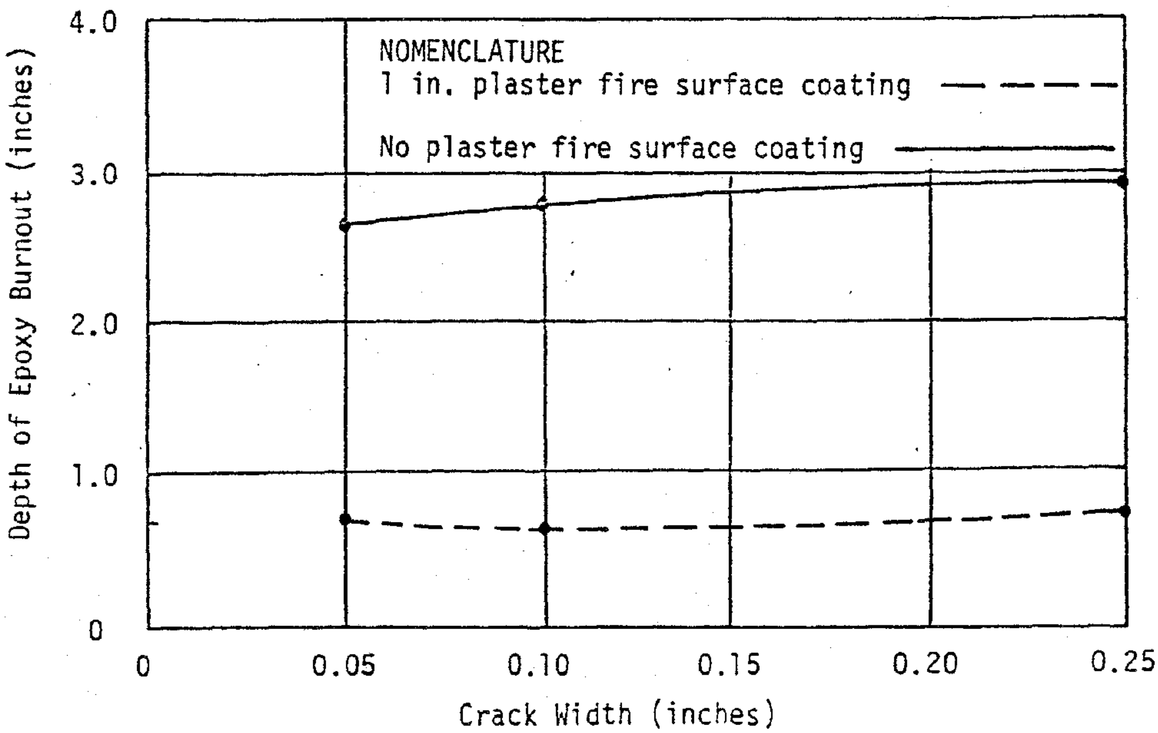

Fig. G-3b: Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page B-2,G-4 in TABLE B-1,G-2

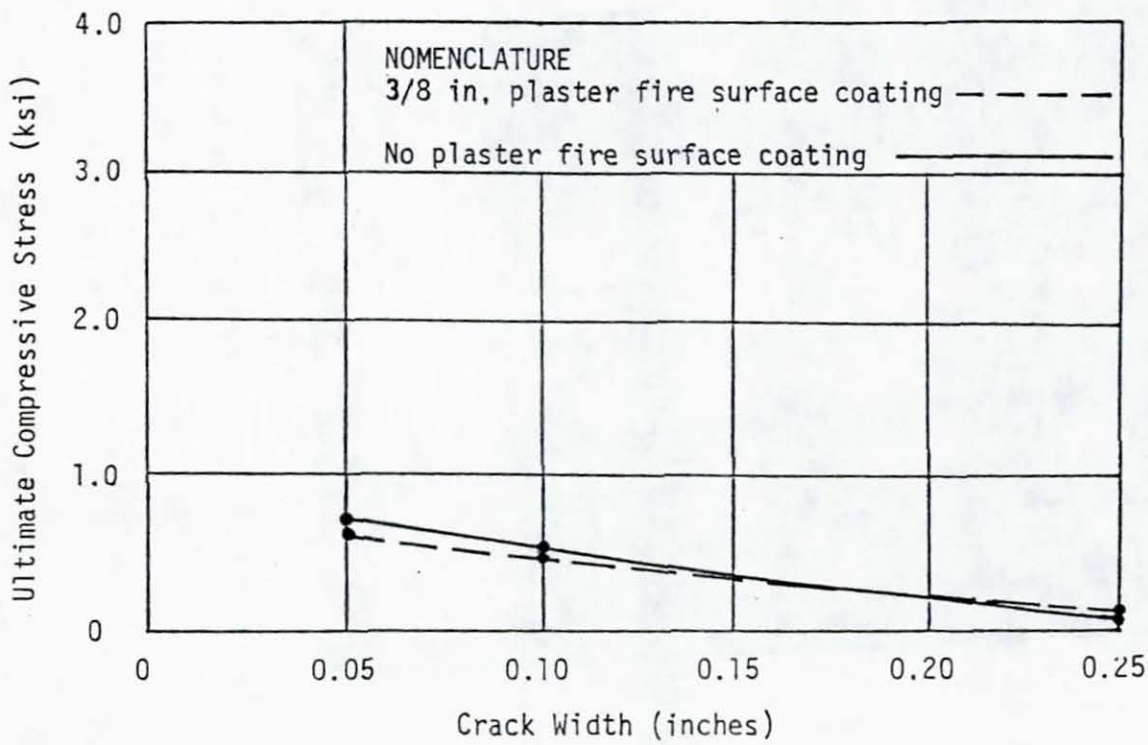

Fig. G-4a : Average Ultimate Compressive Stress as a Function of Crack Width

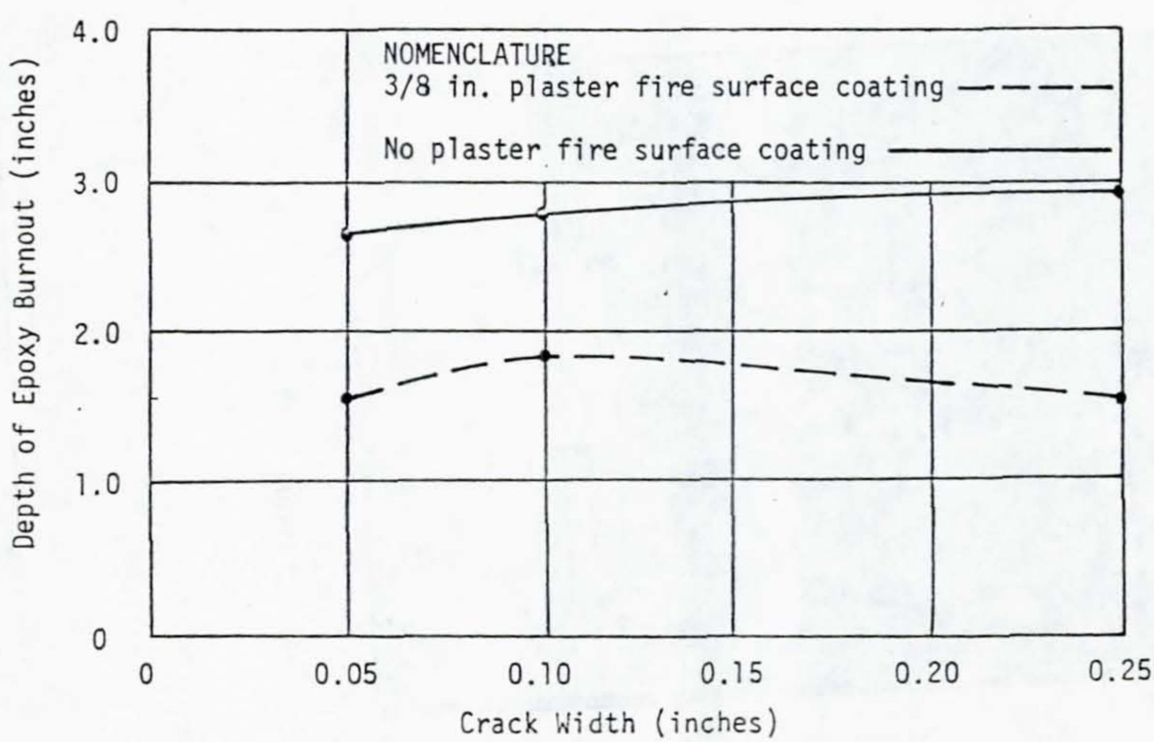

Fig. G-4b : Average Depth of Epoxy Burnout as a Function of Crack Width

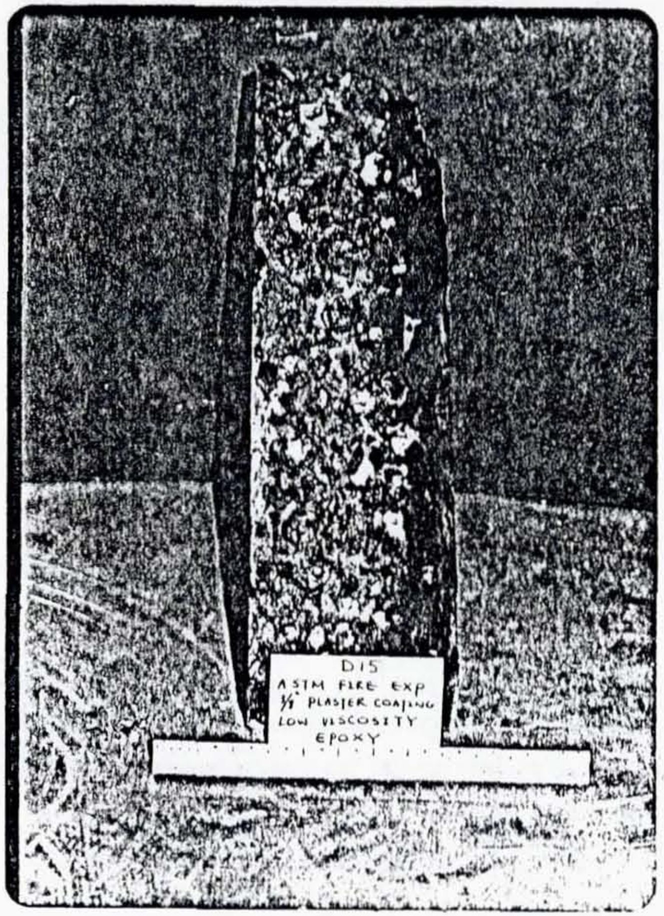

Fig. G-5a : Failure pattern for 6 in. thick Specimen with 3/8 in. Fire surface Coating.

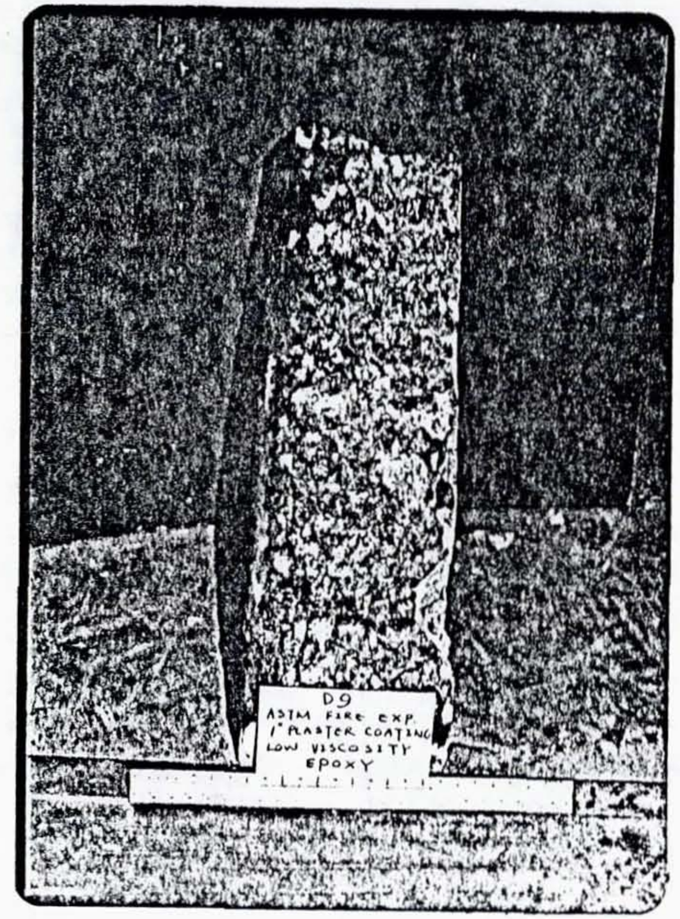

Fig. G-5b : Failure pattern for 6 in. thick Specimen with 1 in. Fire Surface Coating.

CHAPTER H: SMALL SCALE SDHI HOT STRENGTH COMPRESSION TESTS (PLASTER FIRE SURFACE COATING; LOW VISCOSITY EPOXY)

SEC. H.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in this Chapter H have been exposed to the standard SDHI fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in., and 0.25 in., wall thickness of 6 in., and plaster coating on fire exposed surface of 1 in. and 3/8 in. thickness. The plaster was applied to the specimens as described in Chapter A. All specimens have been subjected to the ultimate compression loads immediately after the fire exposure.

SEC. H.2: SUMMARY OF TEST RESULTS

Table H-1 provides the test data and Fig. H-1 provides the corresponding graphical summary for specimens that have had a 1 in. plaster coating applied to the fire exposed surface. Table H-2 provides the test data and Fig. H-2 provides the corresponding graphical summary for specimens that have had a 3/8 in. plaster coating applied to the fire exposed surface. Shear failure through the concrete was the most common type of failure pattern. Comparison of results in this Chapter with corresponding unplastered test results in Chapter C indicates that 1 in. thick plaster coating is extremely effective in reducing depth of epoxy burnout and increasing ultimate compressive stress as illustrated in Fig. H-3. The lower effectiveness of 3/8 in. thick plaster coating is also illustrated in Fig. H-4. Ultimate compressive stress is a funciton of crack width due to the development of higher frictional forces between concrete surfaces in the case of smaller crack widths. Depth of epoxy burnout for all crack widths and for both the 3/8 in. and the 1 in. thick plaster coatings was zero for all test specimens.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot Strength Compression Test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: 1 inch Plaster Coating

TABLE H-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress(ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0	2.167	0	2.417	0	1.280
2	0	2.679	0	1.440	0	1.563
3						
4						
Average	0	2.423	0	1.929	0	1.422
Standard Deviation	0	0.362	0	0.691	0	0.200

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page H-2 in TABLE H-1 .

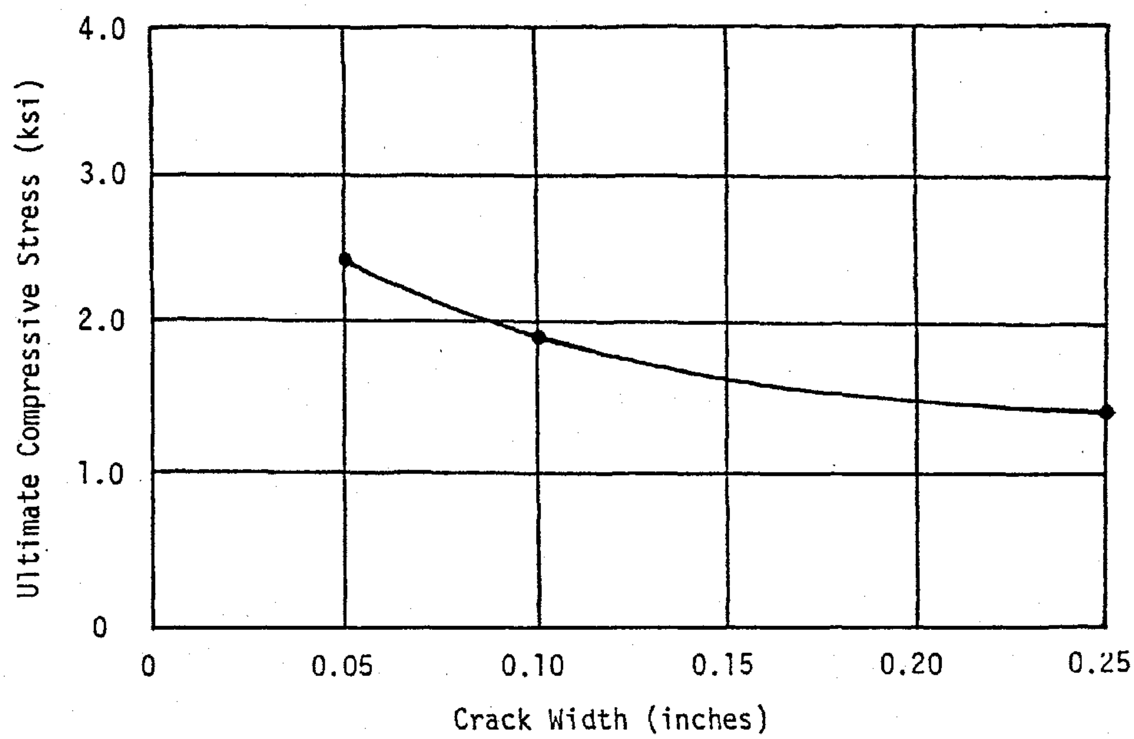

Fig. H-1a : Average Ultimate Compressive Stress as a Function of Crack Width

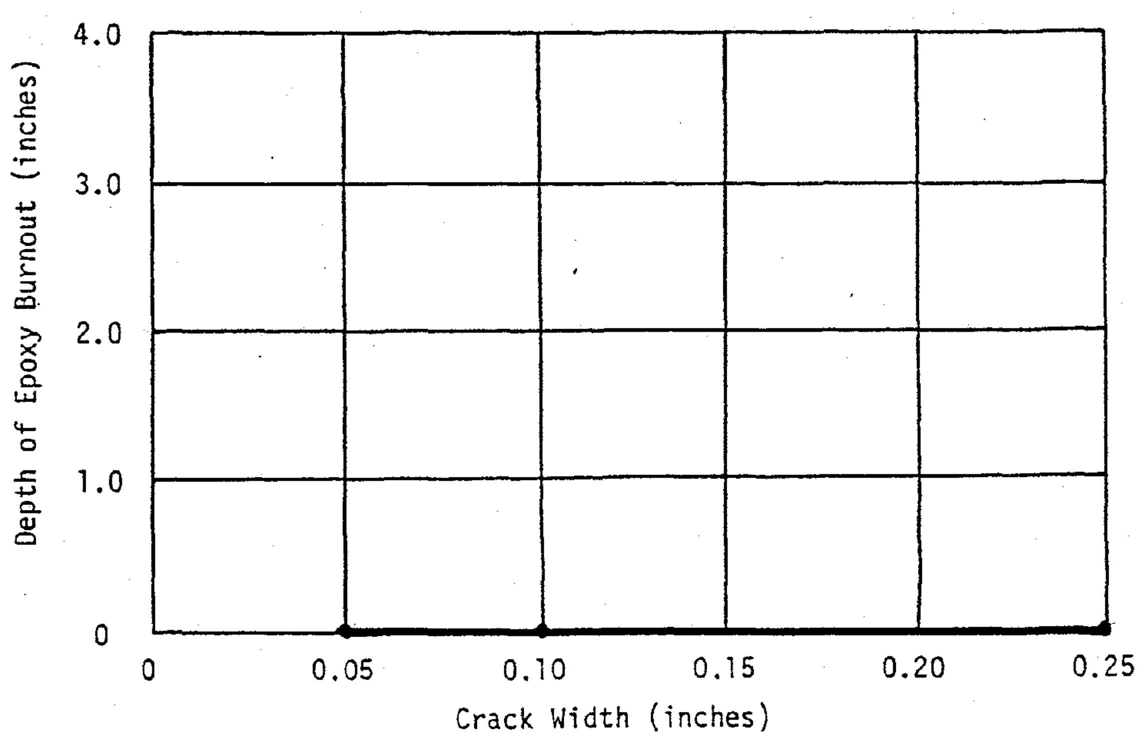

Fig. H-1b : Average Depth of Epoxy Burnout as a Function of Crack Width

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Hot Strength Compression Test

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: 3/8 inch Plaster Coating

TABLE H-2

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress(ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	0.00	1.462	0.00	0.625	0.00	0.599
2	0.00	1.170	0.00	0.814	0.00	0.500
3						
4						
Average	0.00	1.316	0.00	0.720	0.00	0.550
Standard Deviation	0.00	0.206	0.00	0.134	0.00	0.070

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page H-4 in TABLE H-2.

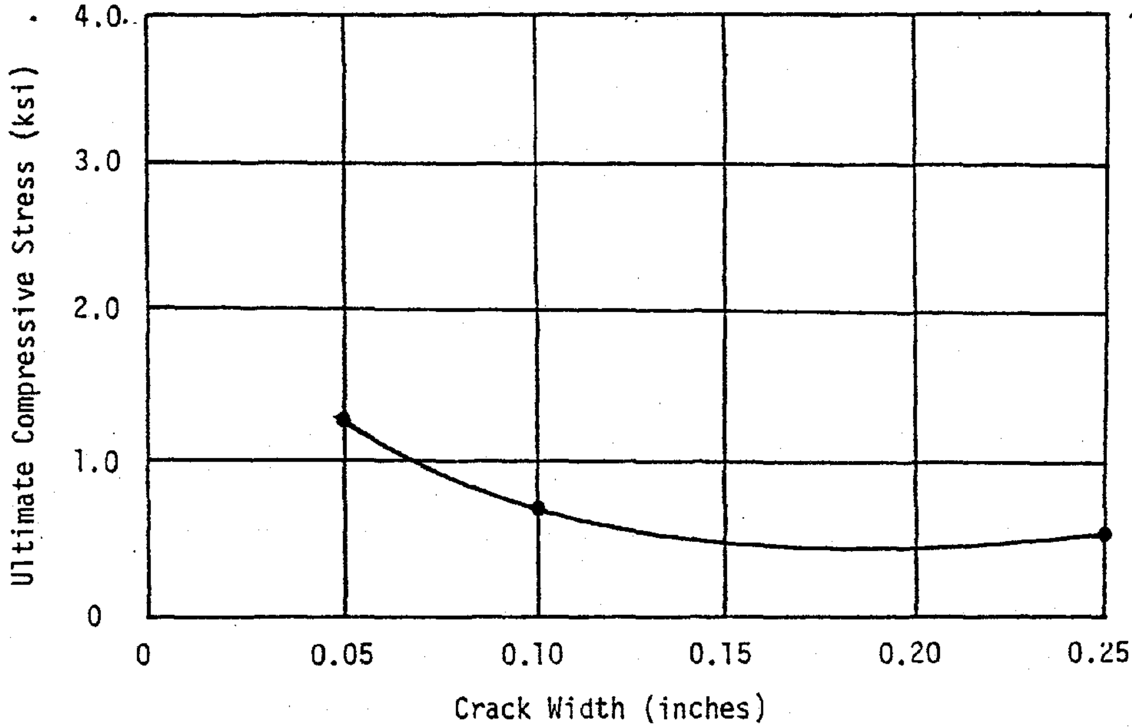

Fig.H-2a : Average Ultimate Compressive Stress as a Function of Crack Width

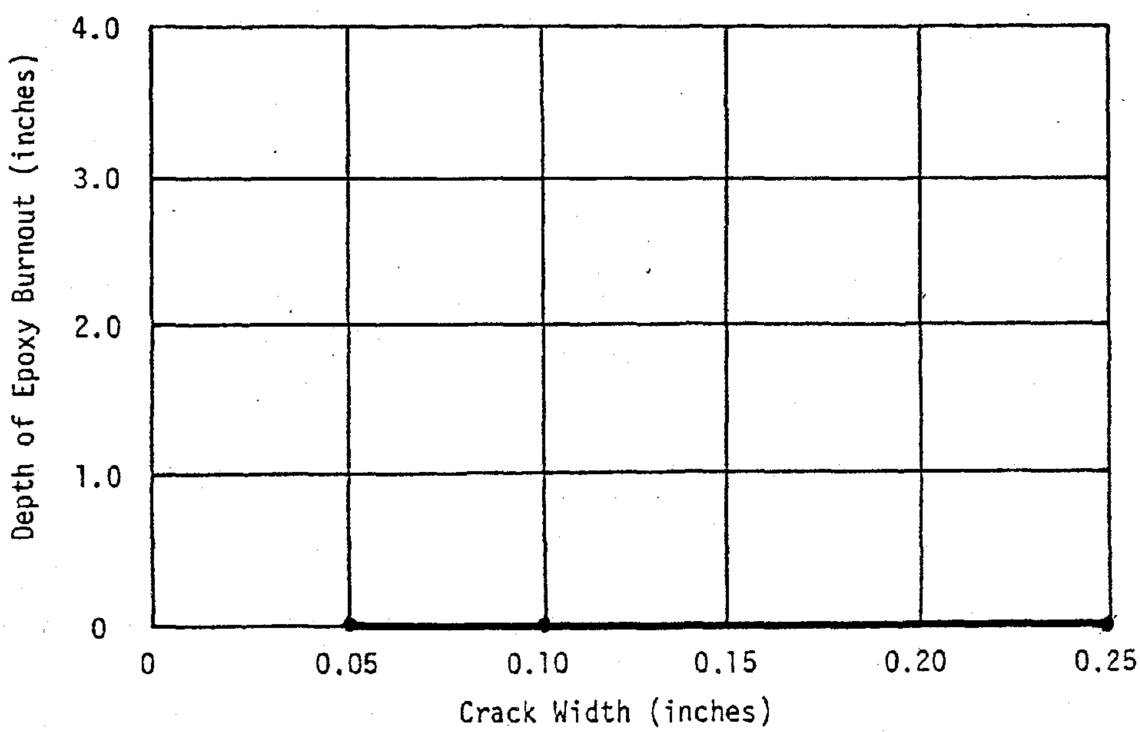

Fig.H-2b : Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page C-2,H-2 in TABLE C-1,H-1

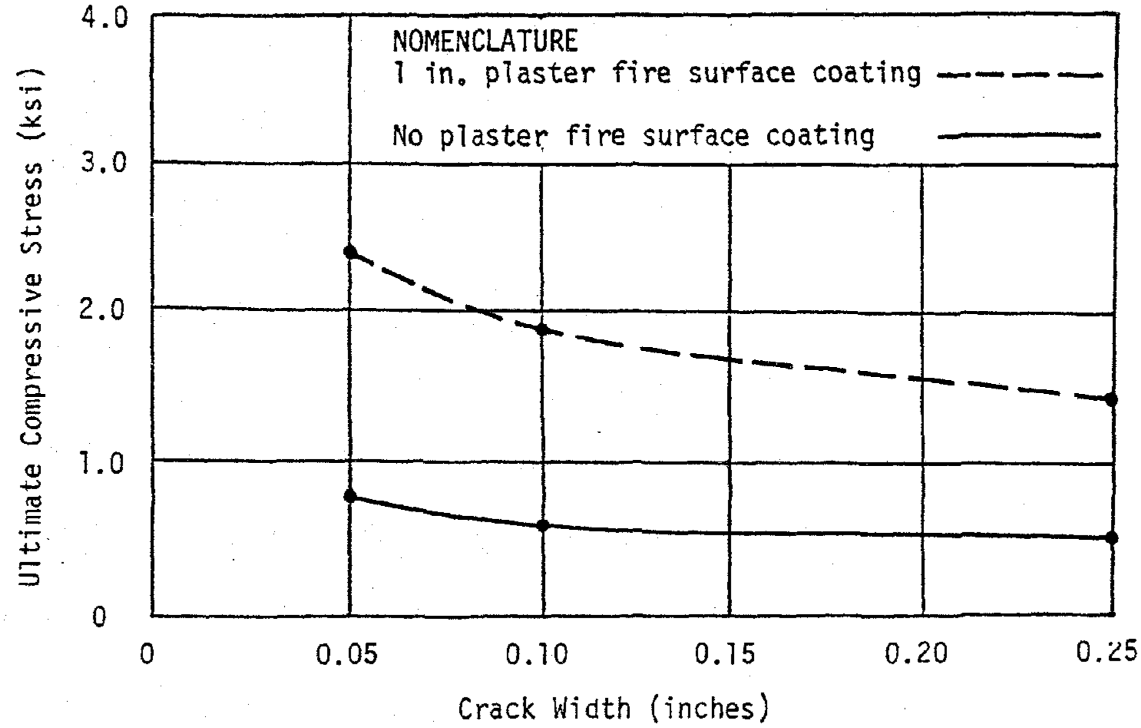

Fig. H-3a: Average Ultimate Compressive Stress as a Function of Crack Width

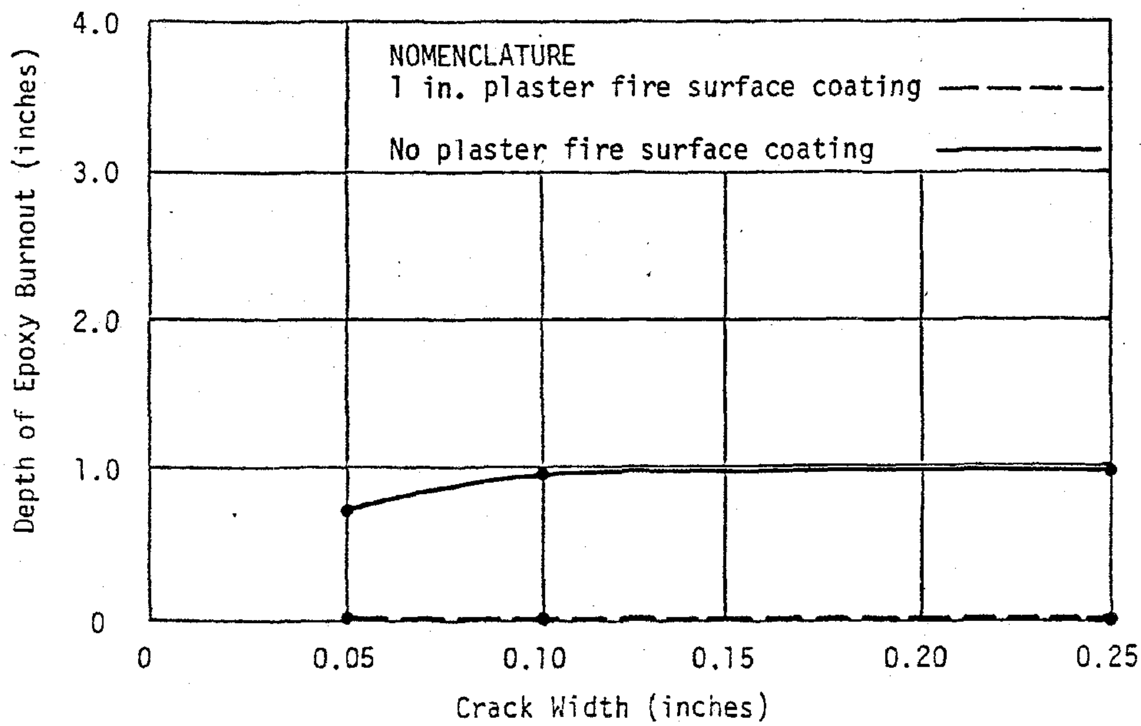

Fig. H-3b: Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

The following graphs illustrate the test results provided on page C-2,H-4 in TABLE C-1,H-2

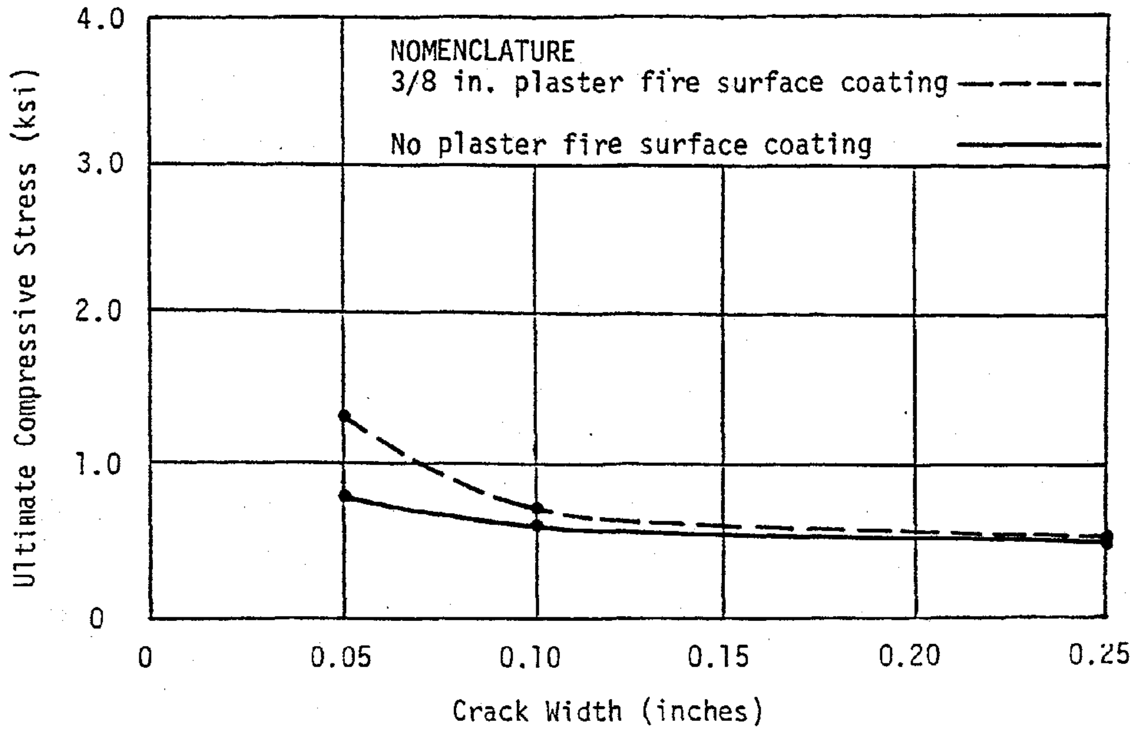

Fig. H-4a: Average Ultimate Compressive Stress as a Function of Crack Width

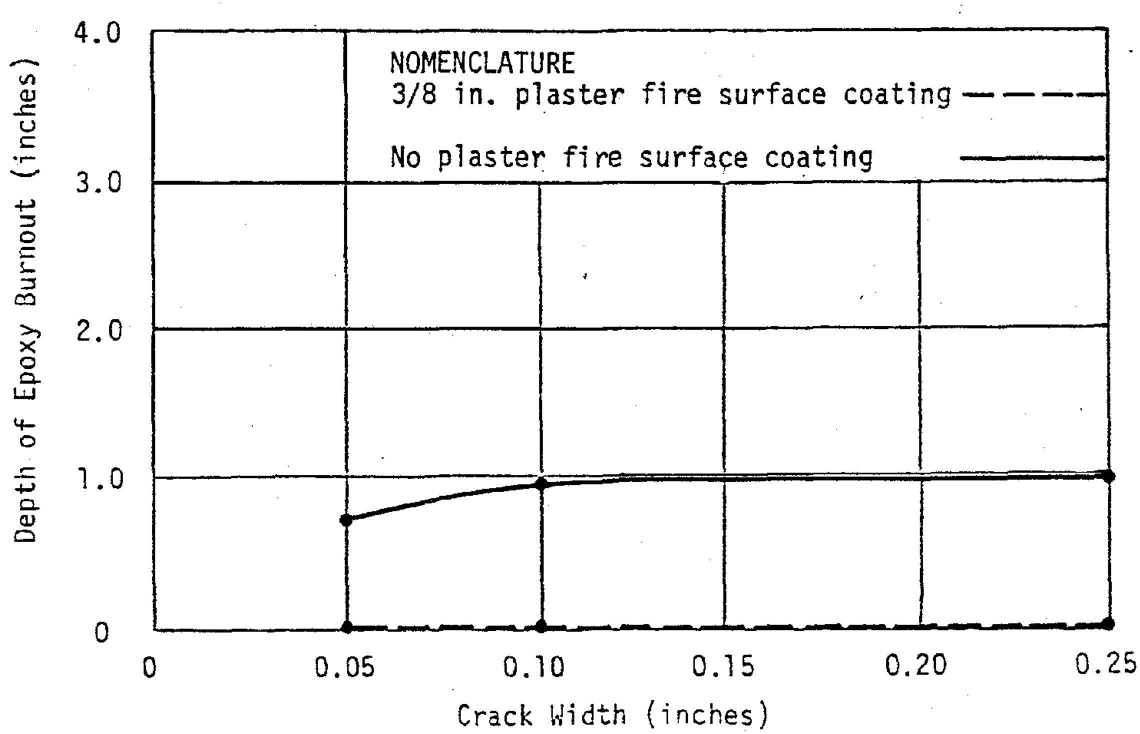

Fig. H-4b: Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

CHAPTER I. SMALL SCALE ASTM E119 HOT STRENGTH COMPRESSION TESTS (ORGANIC FIRE SURFACE COATING; LOW VISCOSITY EPOXY)

SEC. I.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in this Chapter I have been exposed to the standard 2-hour ASTM E119 fire exposure for walls. Primary test parameters studied in this chapter include crack width of 0.10 in., wall thickness of 6 in. and organic fire retardent coatings were applied to the specimens as described in Chapter A. All specimens have been subjected to the ultimate compression loads immediately after the 2-hour fire exposure.

SEC. I.2: SUMMARY OF TEST RESULTS

Table I-1 provides the test data for each specimen including the ultimate compression strength and the depth of epoxy burnout. Comparison of these test results with the uncoated test results in Chapter B indicates that thin organic surface coatings, including both the fire retardant intumescent paints and fire resistant epoxy foams, are not effective fire surface coatings. Fig. I-1 provides pictorial view of the failure pattern which is identical to that for specimens in Chapter B where fire surface coating were not provided.

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SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy

LOAD CONDITIONS: Hot Strength Compression Test

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: Fire Resistant Epoxy Foams, Intumescent paints

CRACK WIDTH : 0.10 in. for all specimens

TABLE I-1

Specimen Number	Thickness of Coating (inches)			
	0.050		0.100	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.67	0.456	2.55	0.625
2	2.95	0.244	2.75	0.423
3	2.75	0.536	2.75	0.244
4				
Average	2.79	0.412	2.69	0.431
Standard Deviation	0.14	0.151	0.11	0.191

Fig. I-1 : Failure pattern for 6 in. Thick Specimen with Organic Fire Surface Coating.

CHAPTER J: SMALL SCALE ASTM E119 AND SDHI RE-INJECTED TESTS (NO FIRE SURFACE COATING; LOW VISCOSITY EPOXY)

SEC. J.1: TEST PROCEDURE AND TEST PARAMETERS

This chapter provides a complete summary of test results for specimens whose dimensions and load application are described in Chapter A. The epoxy used to repair all cracks consisted of low viscosity type epoxies which have been described in Chapter A. All test specimens considered in this Chapter J have been exposed to the standard two-hour ASTM E119 or SDHI fire exposure for walls. Primary test parameters studied in this chapter include crack widths of 0.05 in., 0.10 in. and 0.25 in. and wall thickness of 6 in. Each specimen was subjected to the prescribed fire exposure, cooled for seven days under laboratory conditions, the burnout crack cleaned with pressurized air and a wire brush and subsequently repaired with re-injected low viscosity epoxy adhesives and mortar mix. The repaired specimens were cured for 28 days and tested in compression under laboratory conditions as all other specimens in this report.

SEC. J.2: SUMMARY OF TEST RESULTS

Tables J-1 and J-2 provide the test data for each specimen including the ultimate compression strength and the initial depth of epoxy burnout. Figs. J-1 and J-2 provide the graphical summary of average test results including average ultimate compressive stress and initial depth of epoxy burnout as a function of crack width. The initial depth of epoxy burnout was determined after the specimen had been cooled but prior to re-injection of epoxy adhesives. Results in both Figs. J-1 and J-2 indicate that the ultimate compressive stress of re-injected specimens was not significantly affected by crack width. However, the ultimate compressive stress test results for ASTM E119 fire exposure as given in Fig. J-1 are significantly lower than the SDHI test results in Fig. J-2. Failure pattern for all specimens in this chapter consisted of shear failure in the concrete. Based on the observations of the failed specimens, it appears that re-injection procedures as utilized for these specimens, were extremely effective in the repair of epoxy repaired shear walls which had been subjected to fire exposure.

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy

LOAD CONDITIONS: Compression Test after Re-Injection

TIME-TEMPERATURE FIRE CURVE: ASTM E-119

TYPE OF COATING ON FIRE SURFACE: None

TABLE J-1

Specimen Number	Crack Width (inches)					
	0.05		0.10		0.25	
	Burnout (inches)	Ultimate Compressive Stress (ksi)	Burnout (inches)	Ultimate Compressive Stress(ksi)	Burnout (inches)	Ultimate Compressive Stress (ksi)
1	2.80	3.014	2.85	2.821	3.0	2.595
2	2.50	2.304	3.20	1.804	3.0	2.143
3						
4						
Average	2.65	2.659	3.02	2.313	3.0	2.369
Standard Deviation	0.21	0.502	0.24	0.719	0.0	0.320

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The following graphs illustrate the test results provided on page J-3 in TABLE J-1.

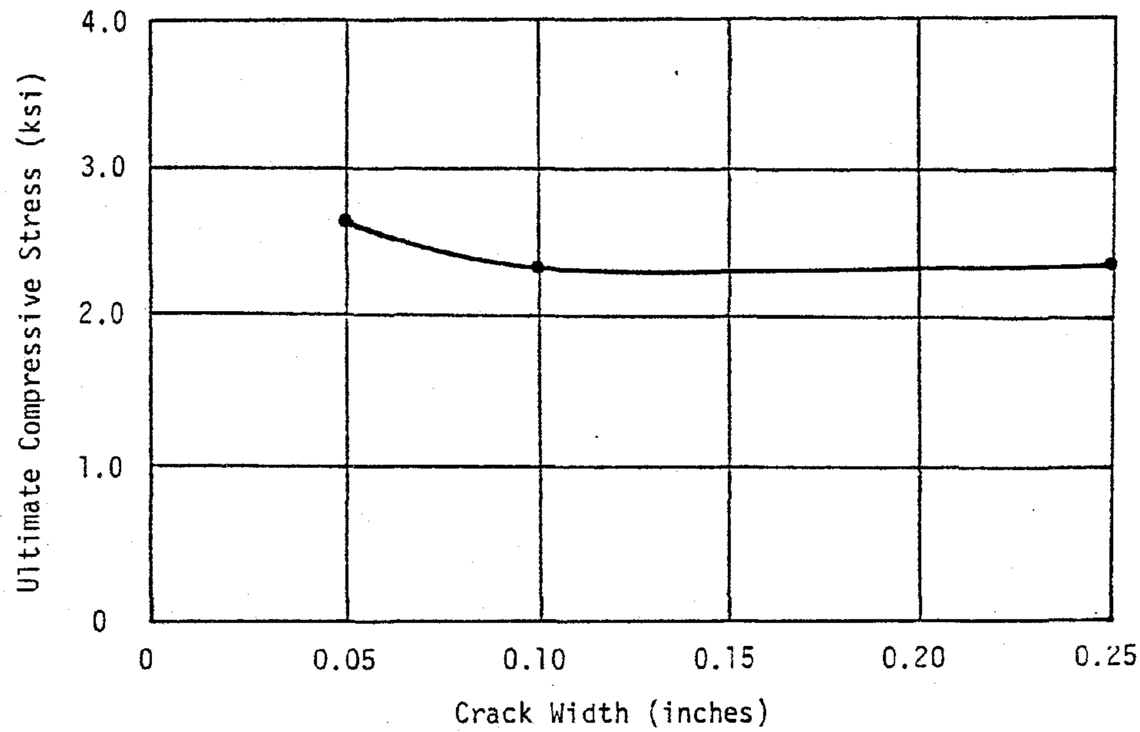

Fig. J-1a: Average Ultimate Compressive Stress as a Function of Crack Width

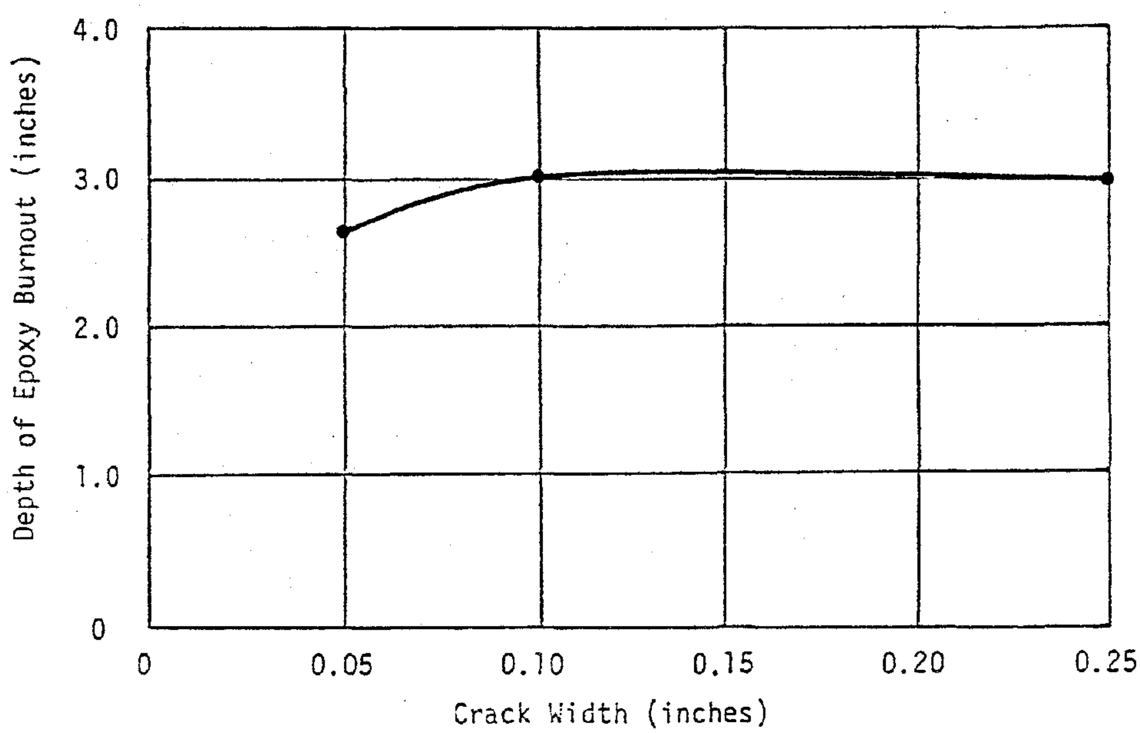

Fig. J-1b: Average Depth of Epoxy Burnout as a Function of Crack Width

STRUCTURES LABORATORY AT CALIFORNIA STATE UNIVERSITY, LONG BEACH

SUMMARY OF EXPERIMENTAL TEST RESULTS

The experimental test results presented in the table below correspond to the following test conditions for the epoxy repaired concrete shear wall specimens.

SPECIMEN SIZE: Width = 14 in.; Height = 18 in.; Thickness = 6 in.

CONCRETE TYPE: Normal Weight; Unreinforced; 4.0 ksi Compressive Strength

EPOXY TYPE: Low Viscosity (400 cps); Structural Grade Epoxy.

LOAD CONDITIONS: Compression Test after Re-Injection

TIME-TEMPERATURE FIRE CURVE: SDHI

TYPE OF COATING ON FIRE SURFACE: None

TABLE J-2

Specimen Number	Crack Width (inches) 0.05 Burnout (inches)	0.05 Ultimate Compressive Stress (ksi)	0.10 Burnout (inches)	0.10 Ultimate Compressive Stress (ksi)	0.25 Burnout (inches)	0.25 Ultimate Compressive Stress (ksi)
1	0.85	3.319	1.42	3.571	1.35	3.333
2	0.79	3.571	1.05	3.512	0.95	3.260
3						
4						
Average	0.82	3.445	1.24	3.542	1.15	3.297
Standard Deviation	0.04	0.178	0.26	0.042	0.28	0.052

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The following graphs illustrate the test results provided on page J-5 in TABLE J-2 .

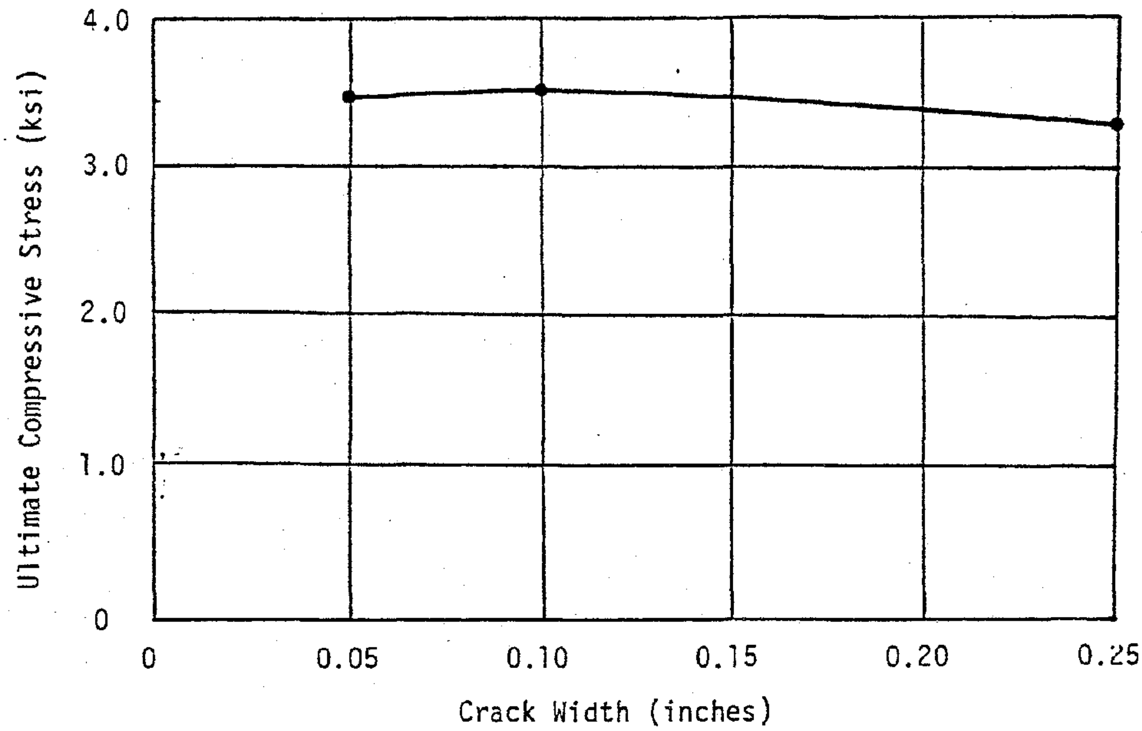

Fig. J-2a : Average Ultimate Compressive Stress as a Function of Crack Width

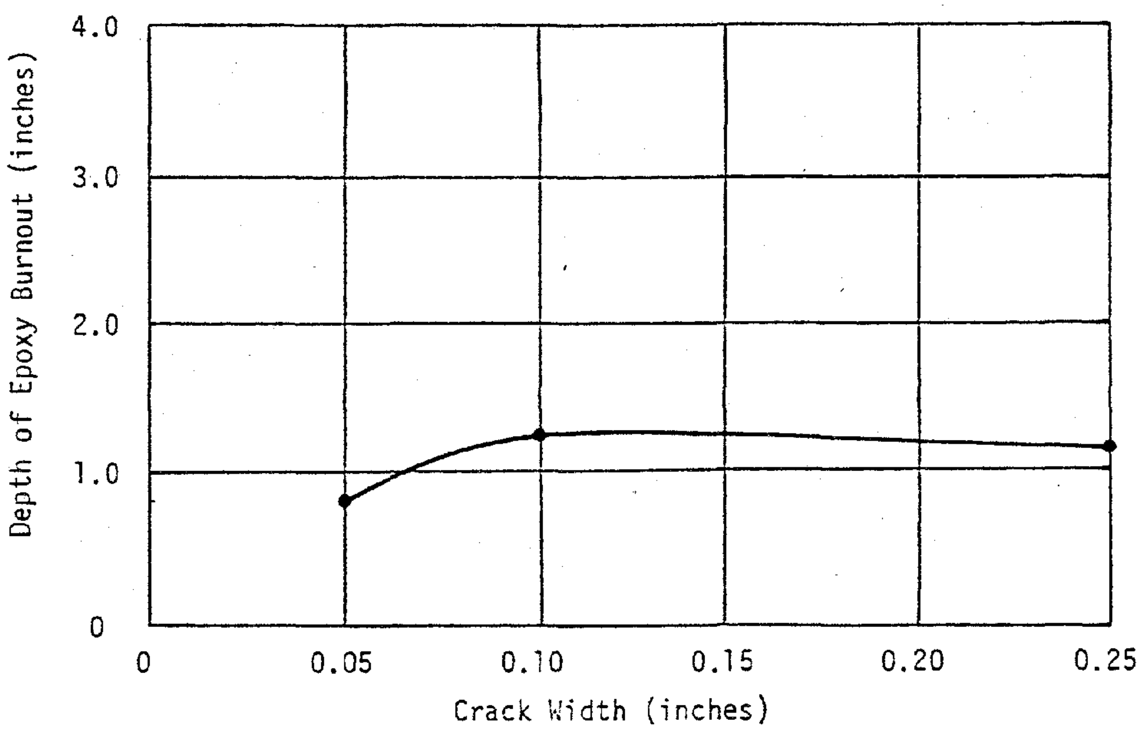

Fig. J-2b: Average Depth of Epoxy Burnout as a Function of Crack Width

CHAPTER K: DESCRIPTION OF FIRE TEST APPARATUS AND PROCEDURE USED FOR INTERMEDIATE AND LARGE-SCALE SPECIMENS

SEC. K.1.0: INTRODUCTION

This chapter describes the fire testing apparatus and procedure used in the tests of shear walls at the University of California, Richmond Field Station, Fire Test Laboratory. Two general size scales were tested: eight (8) intermediate-scale (39-1/2 in. x 34-1/4 in.) and two (2) large-scale (102 in. x 89-1/2 in.) specimens. All of the specimens tested were fabricated at California State University, Long Beach.

The test apparatus and procedure used in conducting the intermediate-scale experiments differed somewhat from that used in the large-scale experiments. Therefore, this chapter will be divided into the following sections: descriptions of the large-scale testing apparatus and procedure, sections K.4.1 and K.4.2, respectfully. The furnace and furnace door assembly, which were used for all of the tests is described in section K.2.0.

SEC. K.2.0: DESCRIPTION OF FURNACE AND FURNACE DOOR ASSEMBLY

Furnace

The test furnace (Figure K-1) consists of a reinforced concrete frame lined with refractory materials and having a door opening twelve feet, one inch (12'1") wide by eleven feet (11') high.

The furnace is fired by 44 gas burners. They are arranged so that the temperature can be maintained in accordance with the standard time-temperature curve as specified by ASTM Designation E-119-73.

SEC. K.3.1: DESCRIPTION OF FIRE TEST APPARATUS FOR INTERMEDIATE-SCALE SPECIMENS

The intermediate-scale (39-1/2" x 34-1/4") specimens were tested in a furnace door assembly similar to the one shown in Figure K-2. Because of the small size of the specimens relative to the large area presented by the furnace door assembly, a testing apparatus had to be fabricated and built into the existing frame. The configuration of the testing apparatus used in these tests is shown in Figure K-3 and described below.

A loading block was constructed in order to elevate the specimen into contact with the top surface of the loading frame. The loading block transfers the load from the loading beam below to the specimen on top. It is composed entirely of wide flanged beams welded together as shown in Figure K-4.

On either side of the loading block are bolted lateral reinforcing members which are also bolted onto the loading beam. These members are composed of two steel angles with their shortside edges welded together as shown in Figure K-5. These two members act to take any lateral load that might result if the specimen was to fail in shear. They also hold the restraint system in place.

To protect against the possibility of the specimen falling out of the test frame a restraint system was developed and is shown in Figure K-6. The fire-side restraint panels adjust to the varying thicknesses of the specimens by sliding forward or backward in the slotted openings in the lateral reinforcing members. Wedges are used to provide a 1/2 in. spacing between the plate face and the side of the specimen. This allows enough space to observe the specimen failing in shear. After the appropriate adjustments are made the panel is bolted into place. The unexposed restraint panels are then bolted into the lateral reinforcing members with steel washers used to give the needed distance from the panel to the back face of the specimen.

Furnace temperatures are measured by nine (9) Type k thermocouples encased in 1/2" standard pipe size inconel sheaths. The thermocouples protrude a minimum twelve (12) inches into the combustion space and can be adjusted to the required six (6) inches from the specimen face. The specific thermocouple placement within the furnace is designated in Figure K-1. Nine (9) fast response thermocouples encased in 1/4" O.D. inconel tubes packed with MgO are used, in addition to the standard ASTM thermocouples, for accurate furnace control during the initial portion of the ASTM test and in conducting the entire Short Duration-High Intensity Test.

All thermocouples are arranged so that the temperature range and average furnace temperatures are accurately determined in accordance with ASTM E-119 specifications.

A uniform draft to all portions of the combustion space is provided by four steel stacks having an inside diameter of fourteen (14) inches and a height of twenty (20) feet above the furnace.

Furnace Door Assembly

The furnace door assembly (Figure K-2) is a steel frame of heavily reinforced I-beams and has a horizontal opening of twelve feet, one inch (12'1") and an adjustable vertical opening. The top and sides of the door are lined with a fire resistive refractory material. The bottom of the frame, on which the test specimen or apparatus rests, is a steel beam. The beam can be adjusted to accommodate various specimen sizes and can be loaded using hydraulic jacks.

The door frame is mounted on an overhead trolley assembly. This system allows the specimen to be prepared for testing in a protected bay. It can then be moved to the furnace for fire testing and then moved outside to cool down.

The remaining area in the test frame is filled with two panels made of light gauge steel studs and channel with structural tubing acting as braces. Brackets were welded onto the top of the side blocking panels to connect the panels to the furnace door assembly. Slots were made in the brackets to allow vertical movement of the panel while the loading beam is raised or lowered. Figure K-7 is a detailed drawing of the side blocking.

All of the exposed steel framework was insulated with two (2) layers of 1-1/2 in. thick, 6 lb/ft^3 density, ceramic fiber blanket. The blankets were anchored across the framework in 2 ft. wide strips using a stainless steel stud and washer system as shown in Figure K-6. A layer of the material also ran along the top surfaces of the side blocking and lateral reinforcing members to stop up the 1 in. gap that exists between the top of the side members and the top of the frame. This gap allows the specimen to shear along the epoxy repaired crack with the load still applied to it. The ceramic fiber is a spongy material that deforms easily under a load so it does not transfer the applied load to the side members on which it rests.

SEC. K.3.2: TEST PROCEDURE FOR INTERMEDIATE-SCALE SPECIMENS

Prior to mounting the specimen into the test frame, small samples of the plaster coating were taken both from the surface and mid-depth to determine the moisture content at these locations. The coating was then repaired of any cracks or holes at least 24 hours before the test.

Two (2), thirty (30) ton capacity, hydraulic jacks were used to provide a load of 45 kips on the specimen. Calculations made prior to the test determined the dead load of the wall and testing apparatus to be 2,600 lb. with the resulting total load being 47.6 kips. This load was applied by means of a hydraulic hand pump.

The load was monitored throughout the test with a gauge that had previously been calibrated with the jacks on a hydraulic press.

The temperature of the unexposed face of the west wall was obtained by a thermocouple held securely against the surface. The thermocouple was tightly covered with a standard asbestos pad meeting ASTM E-119 specifications.

While conducting the intermediate-scale specimen program two different time-temperature curves were used in operating the furnace. Five of the specimens were tested according to the two-hour ASTM E-119 fire test curve which is represented in Figure K-8. The other three specimens were subjected to a 1-hour, Short Duration-High Intensity (SDHI) fire test curve as shown in Figure K-9. The deviation of the area contained under the observed curve from the standard curve was calculated for each test and is presented along with the other test results in Chapter L.

If the hydraulic pressure reading for the jacks began to drop off rapidly during the test, failure was assumed to have taken place along the epoxy-repaired crack. After visual confirmation, the load was reduced while the fire test proceeded. If the specimen did not fail during the fire test the load was maintained while the test frame was rolled away from the furnace and monitored for failure until it has cooled down.

SEC. K.4.1: <u>DESCRIPTION OF FIRE TEST APPARATUS FOR LARGE-SCALE SPECIMENS</u>

The large-scale (102" x 89-1/2") specimens were tested in the same furnace door assembly as the intermediate-scale specimens (Figure K-2). The width of the large-scale wall was narrower than that present in the furnace door assembly so a testing apparatus was fabricated and built into the existing frame. The configuration of the testing apparatus used in the large-scale tests is shown in

Figure K-10 and described below.

The lateral reinforcing members used in the intermediate-scale tests (Figure K-5) were bolted onto steel stands which were then bolted onto the loading beam on either side of the wall. A gap of one (1) in. was left between the sides of the wall and each lateral reinforcing member. This space allowed sections of the wall horizontal movement if they failed along the epoxy-repaired crack.

To prevent any section of the wall from falling out of the test frame a restraint system was used and is also shown in Figure K-10. Anchors were first sunk into each quadrant of the wall and eye bolts screwed into the anchors. Steel cables were then run between plates welded above and below the frame opening. A shackle was secured around each cable and the eye bolt. The cable was then made taut using a turnbuckle.

The remaining area in the test frame is filled with two panels made of light gauge steel studs and channel. Brackets welded onto the top of each panel connected the panel to the furnace door assembly. Slots made in the brackets allow vettical movement of the panel while the loading beam is raised or lowered.

All of the exposed steel framework was insulated with two (2) layers of 1-1/2 in. thick, 6 lb/ft^3 density, ceramic fiber blanket. The blankets were anchored across the steel framework in two (2) ft. wide strips using a stainless steel stud and washer system. A layer of the material also ran across the top surfaces of the side blocking and lateral reinforcing members. This layer provides a flexible gasket in the needed one (1) in. gap between the top of the side members and the top of the frame.

SEC. K.4.2: TEST PROCEDURE FOR LARGE-SCALE SPECIMENS

Prior to loading the specimen into the test frame, small samples of the plaster coating were taken both from the surface and mid-depth to determine the moisture content at these locations. The coating was then repaired of any cracks or holes at least 24 hours before the test.

Two (2), thirty (3) ton capacity, hydraulic jacks were used to provide a load of sixty (60) kips on the specimen. Calculations made prior to the tests determined the dead load of the wall and testing apparatus to be 4,800 lb. for G-9 and 6,400 lb. for G-10. The resulting total loads supplied by the jacks to G-9 and G-10 were 64.8 kips and 66.4 kips, respectfully. This load was applied by means of a hydraulic hand pump and monitored throughout the test with a gauge that had previously been calibrated with the jacks on a hydraulic press.

Measurements of the temperature rise on the unexposed face of the wall were made at four locations. A thermocouple, tightly covered with a standard asbestos pad meeting ASTM E-119 specifications, was placed on each of the four sections which make up the wall.

Both of the large-scale specimens were tested using the 2-hour ASTM E-119 fire test curve which is shown in Figure K-8. The deviation of the area contained under the observed curve from the standard curve was calculated for each test and is presented along with the other test results in Chapter M.

If the hydraulic pressure reading for the jacks began to drop off rapidly during the test, failure was assumed to have taken place along one of the epoxy repaired cracks. After a visual confirmation, the load was reduced while the fire test proceeded.

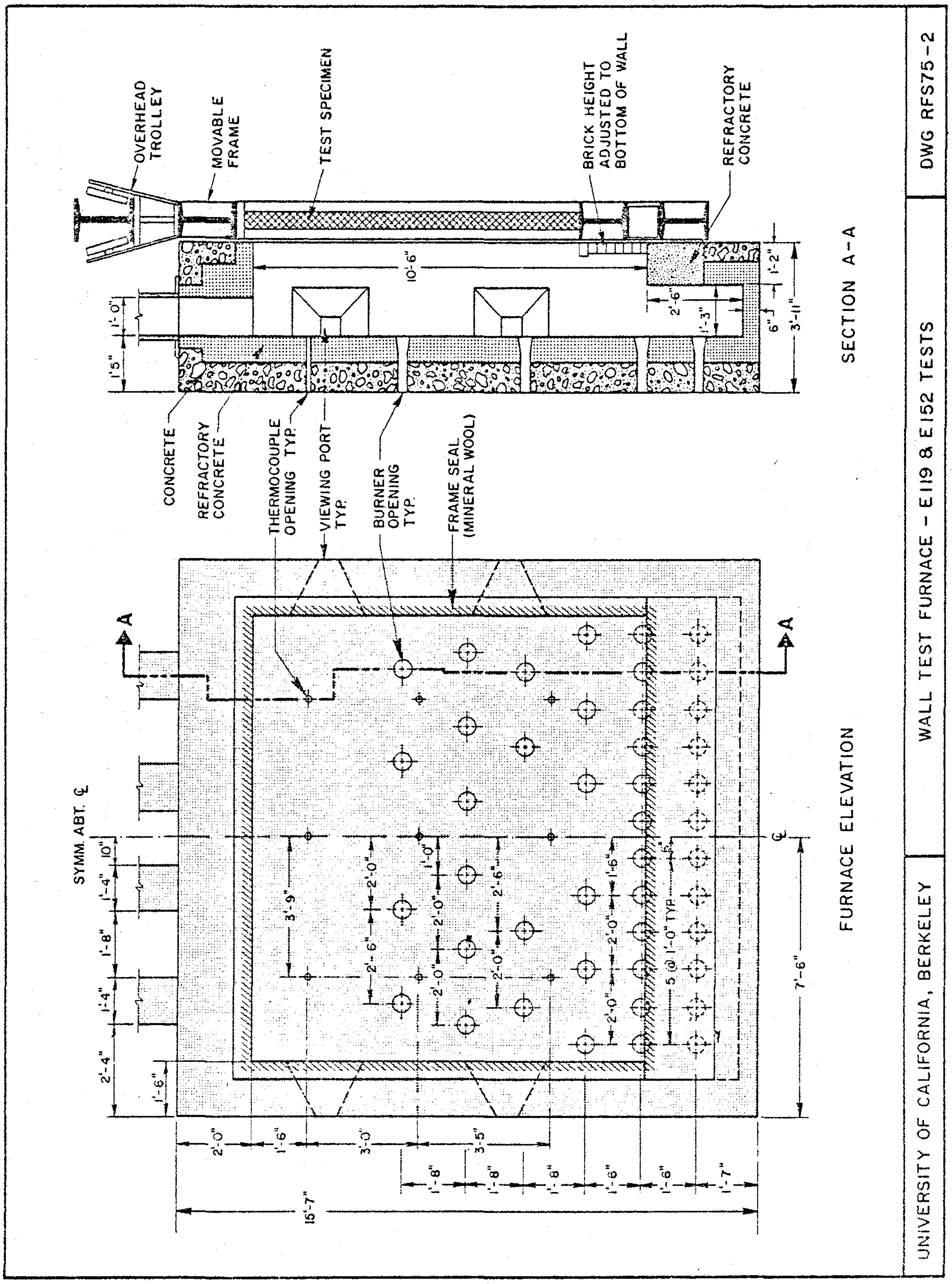
OVERHEAD TROLLEY
MOVABLE FRAME
TEST SPECIMEN
BRICK HEIGHT ADJUSTED TO BOTTOM OF WALL
REFRACTORY CONCRETE
10'-6"
1'-0"
1'5"
2'-6"
1'-3"
1'-2"
6"
3'-11"
SECTION A-A
CONCRETE
REFRACTORY CONCRETE
THERMOCOUPLE OPENING TYP.
VIEWING PORT TYP.
BURNER OPENING TYP.
FRAME SEAL (MINERAL WOOL)
A
A
SYMM. ABT. ℄
10"
1'-4"
1'-8"
1'-4"
2'-4"
1'-6"
3'-9"
2'-6"
2'-0"
2'-0"
2'-0"
1'-0"
2'-6"
2'-0"
1'-6"
2'-0"
2'-0"
5 @ 1'-0" TYP.
6"
7'-6"
℄
FURNACE ELEVATION
2'-0"
1'-6"
3'-0"
3'-5"
1'-8"
1'-8"
1'-8"
1'-6"
1'-6"
1'-7"
15'-7"
UNIVERSITY OF CALIFORNIA, BERKELEY
WALL TEST FURNACE - E119 & E152 TESTS
DWG RFS75-2

FIGURE K-1

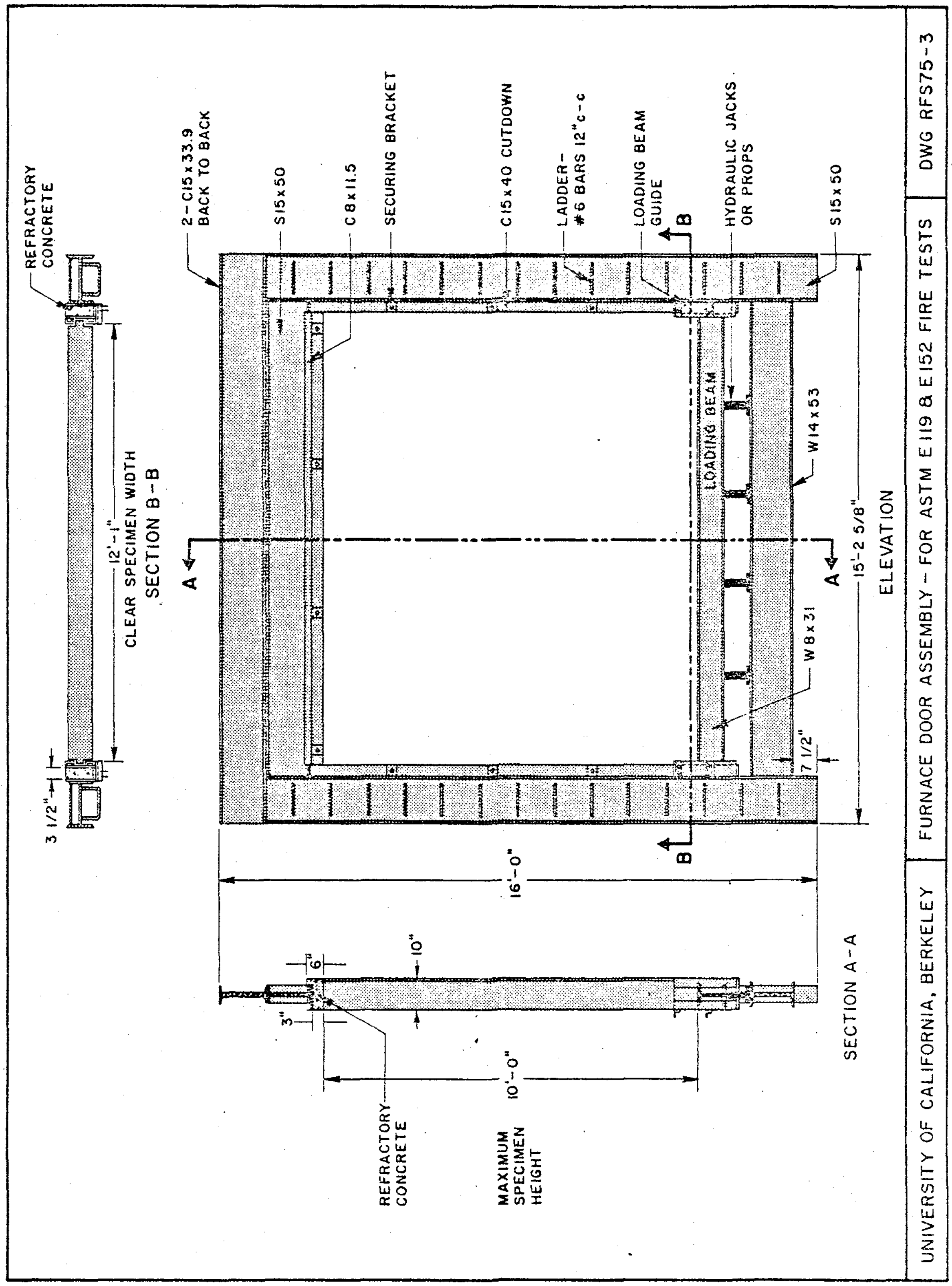
UNIVERSITY OF CALIFORNIA, BERKELEY
FURNACE DOOR ASSEMBLY - FOR ASTM E119 & E152 FIRE TESTS
DWG RFS75-3
REFRACTORY CONCRETE
12'-1"
CLEAR SPECIMEN WIDTH
SECTION B-B
3 1/2"
2-C15x33.9 BACK TO BACK
S15x50
C8x11.5
SECURING BRACKET
C15x40 CUTDOWN
LADDER- #6 BARS 12" c-c
LOADING BEAM GUIDE
HYDRAULIC JACKS OR PROPS
S15x50
LOADING BEAM
W14x53
W8x31
7 1/2"
15'-2 5/8"
ELEVATION
16'-0"
SECTION A-A
10"
6"
3"
10'-0"
REFRACTORY CONCRETE
MAXIMUM SPECIMEN HEIGHT

FIGURE K-2

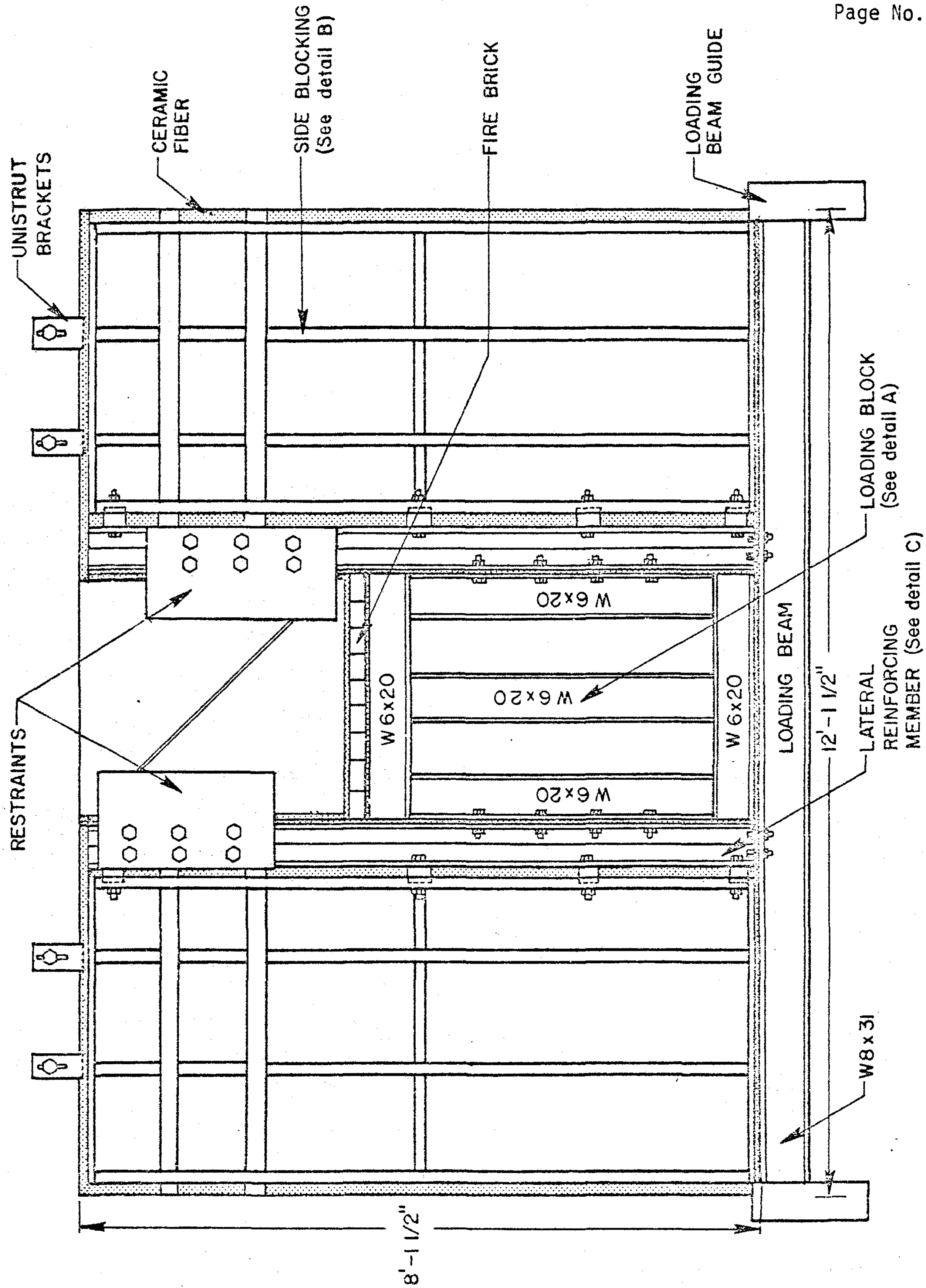
UNISTRUT BRACKETS
CERAMIC FIBER
SIDE BLOCKING (See detail B)
FIRE BRICK
LOADING BEAM GUIDE
LOADING BLOCK (See detail A)
LATERAL REINFORCING MEMBER (See detail C)
RESTRAINTS
W 6x20
W 6x20
W 6x20
W 6x20
W 6x20
LOADING BEAM
12'-1 1/2"
W8 x 31
8'-1 1/2"

FIGURE K-3

LOADING BLOCK
DETAIL A

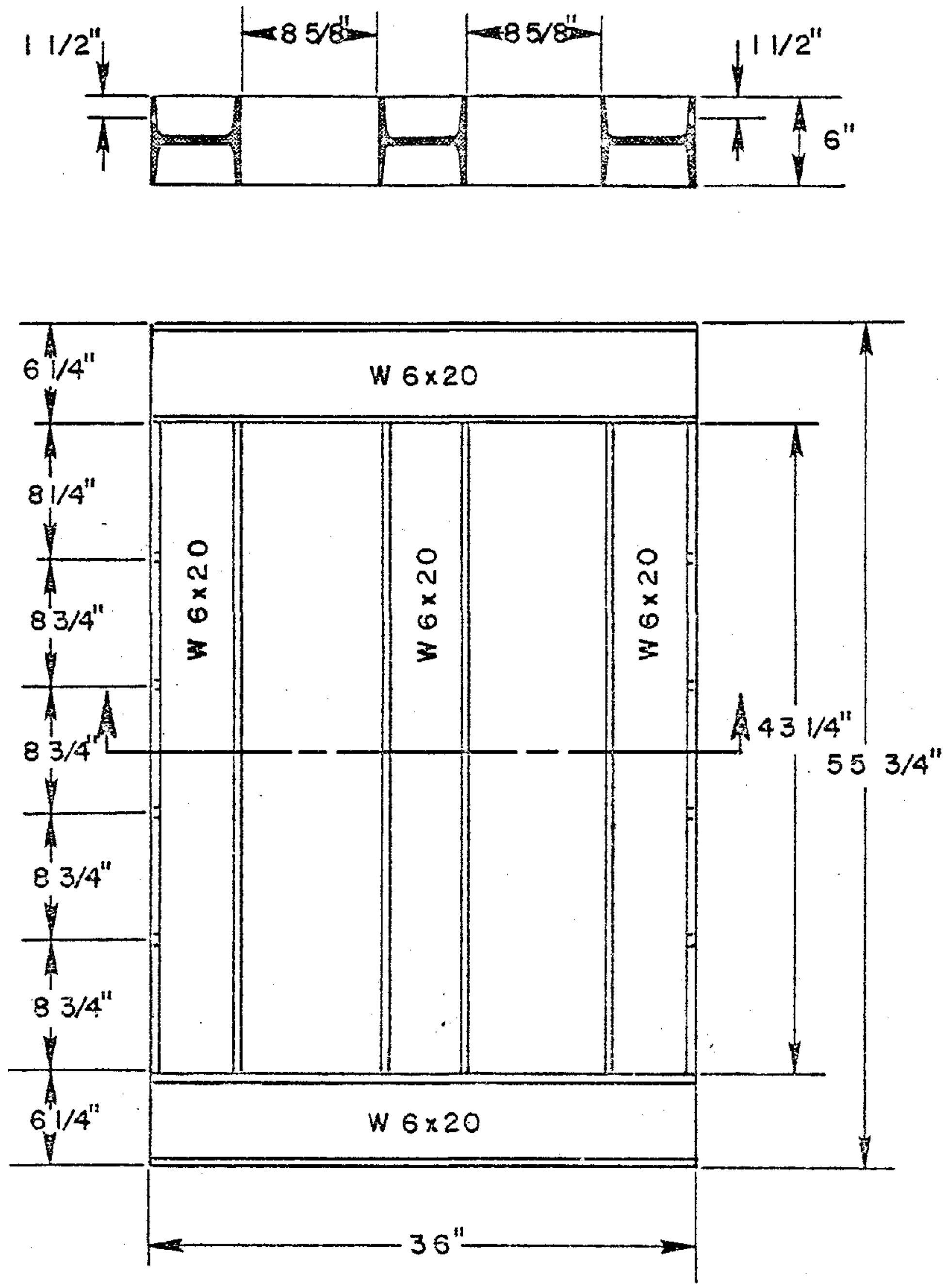

FIGURE K-4

LATERAL REINFORCING MEMBER
DETAIL C

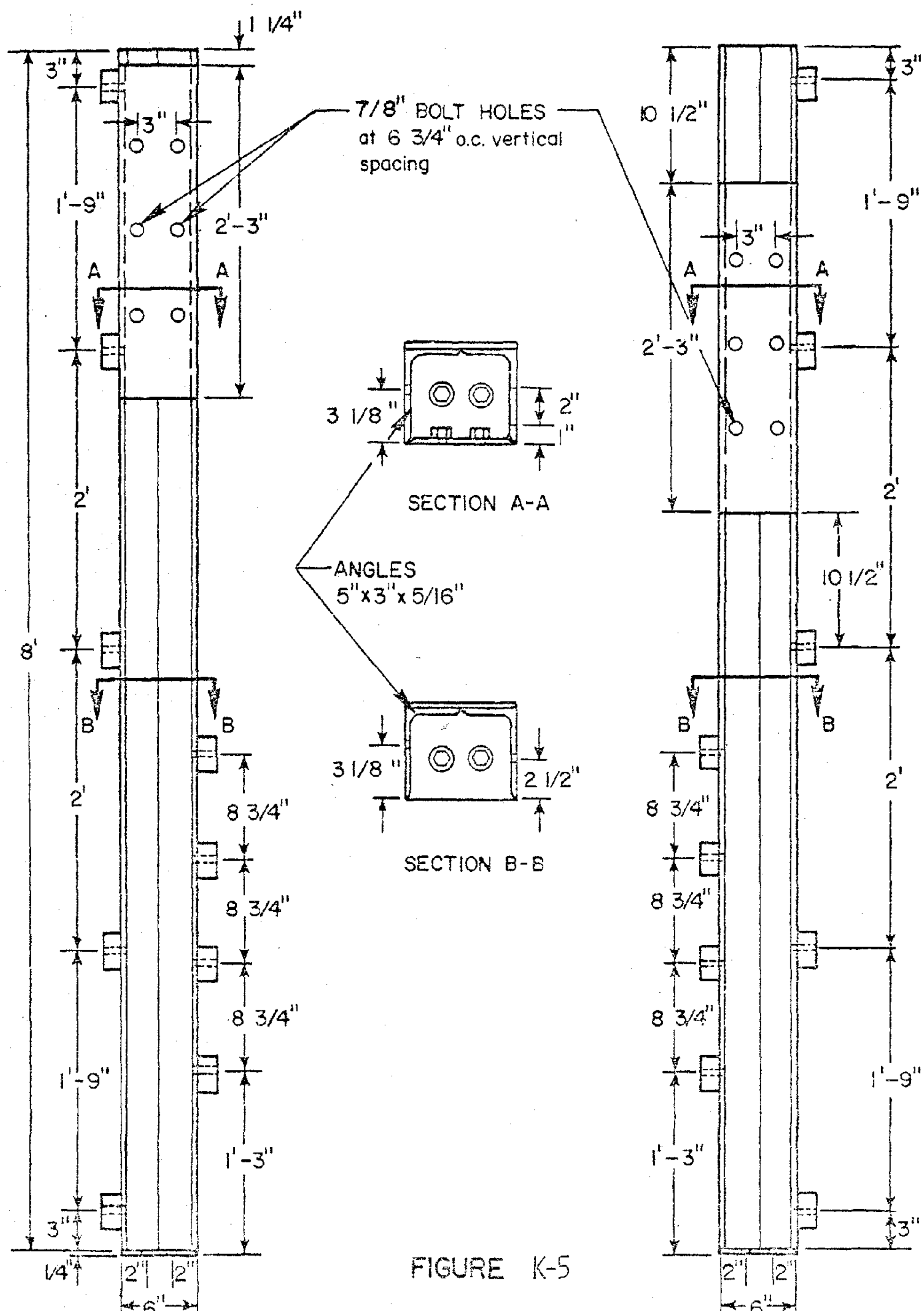

FIGURE K-5

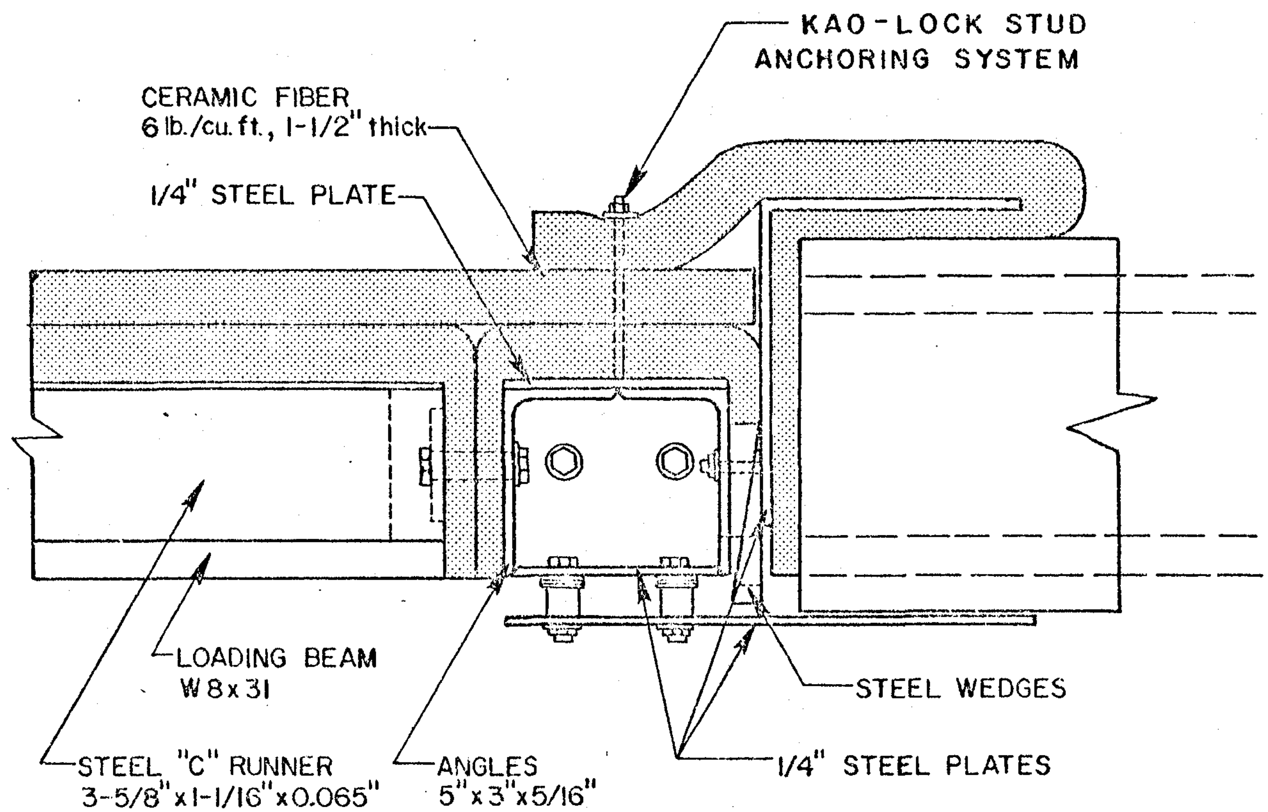
KAO-LOCK STUD
ANCHORING SYSTEM
CERAMIC FIBER
6 lb./cu. ft., 1-1/2" thick
1/4" STEEL PLATE
LOADING BEAM
W 8 x 31
STEEL WEDGES
STEEL "C" RUNNER
3-5/8" x 1-1/16" x 0.065"
ANGLES
5" x 3" x 5/16"
1/4" STEEL PLATES

FIGURE K-6

SIDE BLOCKING
DETAIL B

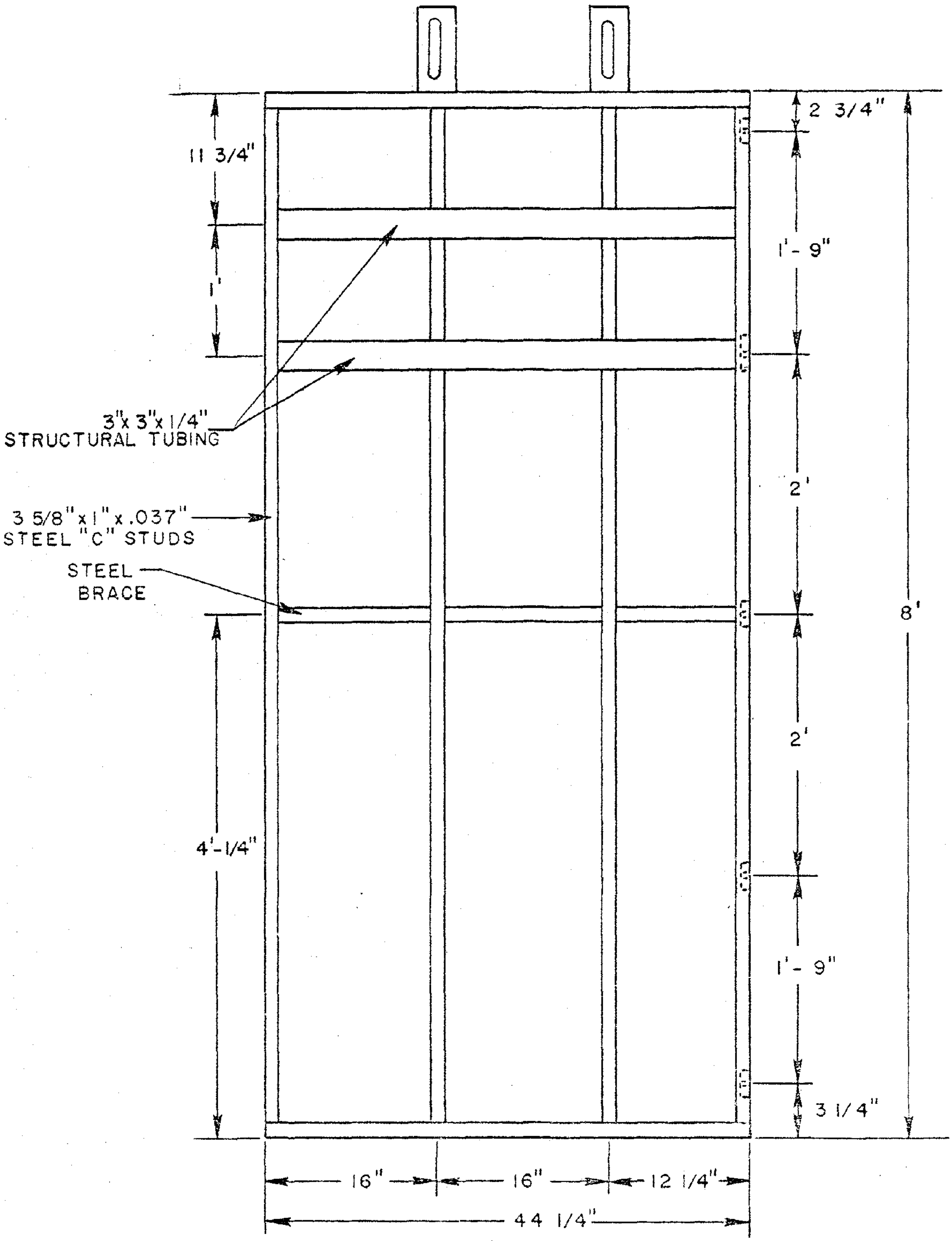

FIGURE K-7

FURNACE TEMPERATURE

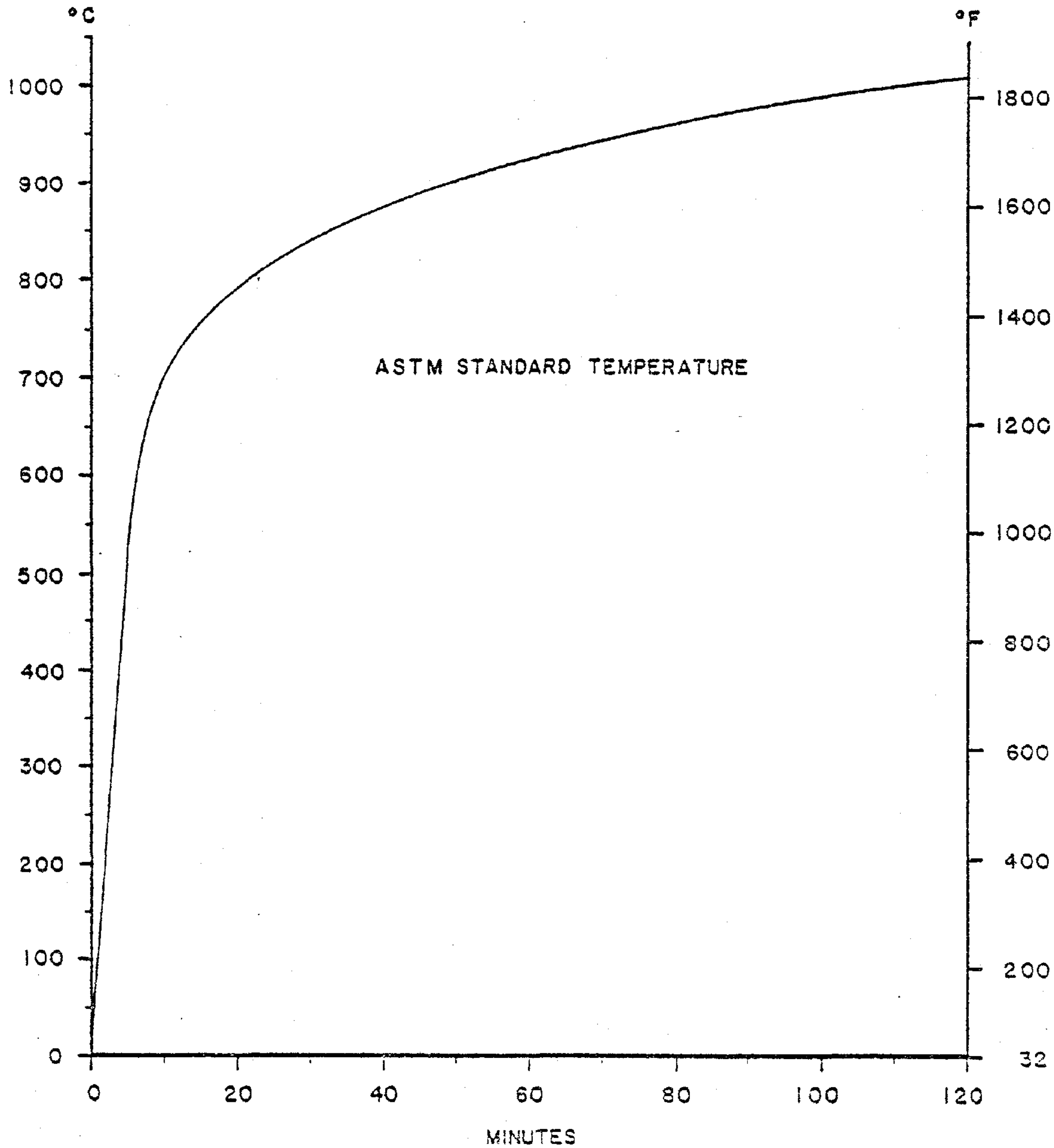

FIGURE K-8

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SHORT DURATION HIGH INTENSITY (SDHI) FIRE TEST CURVE

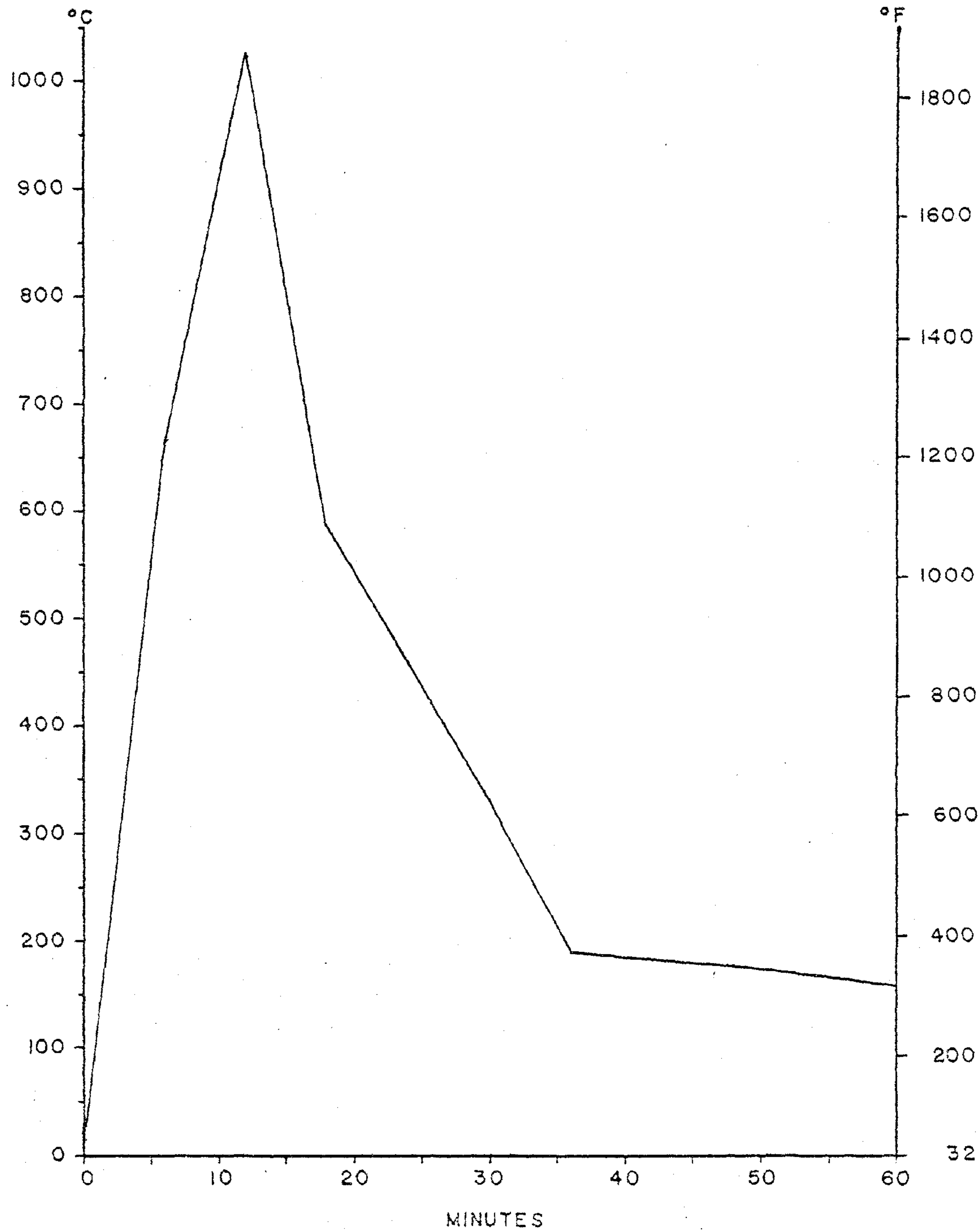
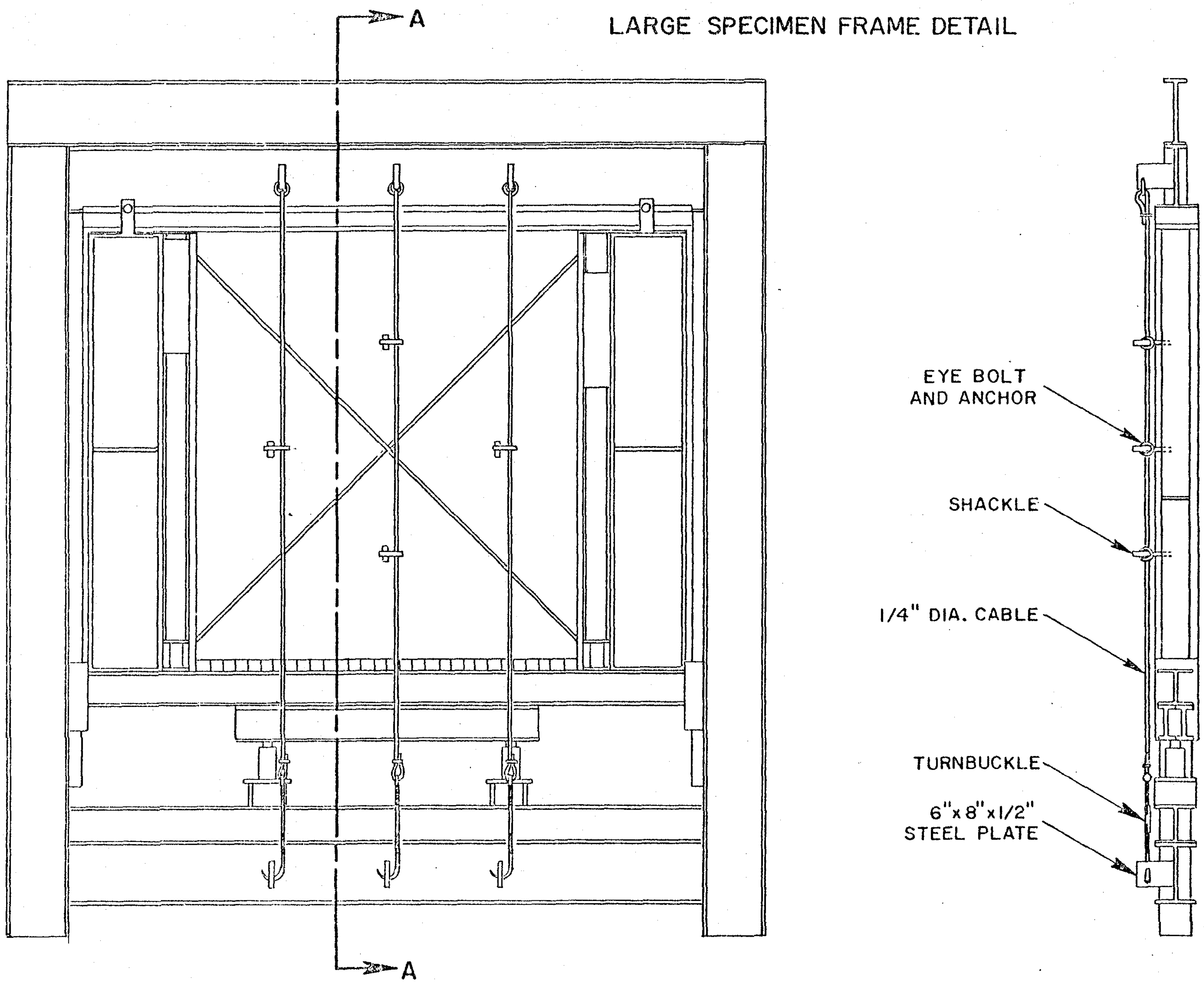


FIGURE K-9

LARGE SPECIMEN FRAME DETAIL



ELEVATION FIGURE K-10 SECTION A-A

SDHI TIME TEMPERATURE CURVE*

TIME (min)	TEMP (°C)	TIME (min)	TEMP (°C)
0	20	31	307
1	123	32	284
3	338	33	260
4	446	34	236
5	553	35	213
6	661	36	189
7	722	36	188
8	783	38	187
9	844	39	186
10	904	40	185
11	965	41	184
12	1026	42	183
13	953	43	182
14	880	44	181
15	807	45	180
16	733	46	179
17	660	47	178
18	587	48	177
19	566	49	175
20	545	50	174
21	524	51	172
22	503	52	170
23	482	53	169
24	461	54	167
25	439	55	166
26	418	56	164
27	396	57	163
28	374	58	161
29	353	59	160
30	331	60	158

*All values at 6 minute intervals estimated from p. 12 of FRG 76-12. All intermediate values obtained through linear interpolation.

TABLE K-1

CHAPTER L: EXPERIMENTAL TEST RESULTS OF INTERMEDIATE-SCALE SPECIMENS

SEC. L.1.0: INTRODUCTION

This chapter contains the experimental test results obtained from fire tests on intermediate-scale epoxy repaired shear wall specimens of the dimensions shown in Figure L-1. The designation number used to identify each specimen along with the specimens physical characteristics and the time-temperature curve used during the testing procedure is presented in Table L-1. These tests were conducted at the University of California, Richmond Field Station, Fire Test Laboratory, between the dates of November 27, 1979 and December 14, 1979. The test apparatus and procedure used in carrying out these tests is described in section K.2.1 and section K.2., respectfully.

The remainder of this chapter is sectioned according to the results obtained from each experiment. Each section contains a description of the specimen before the test and the conditions under which it was tested. Also contained in the results is a log of visual observations taken during the experiment and a sketch of the cross-section of the epoxy repaired crack after the test was completed.

INTERMEDIATE-SCALE WALL SPECIMENS

FIGURE L-1

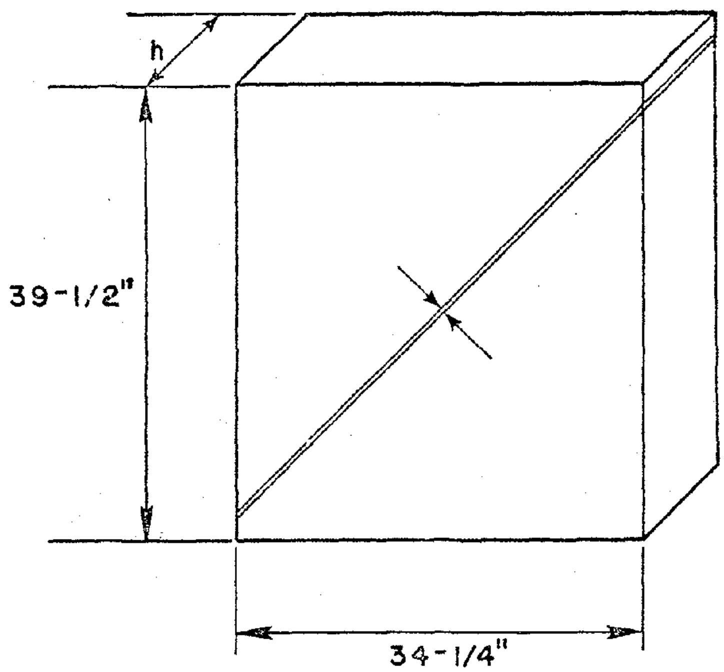


TABLE L-1

SPECIMEN NUMBER	THICKNESS, h* INCHES)	CRACK WIDTH (INCHES)	PLASTER COATING (INCHES)	TIME-TEMPERATURE CURVE
G-1	7	0.05	1	ASTM
G-2	10	0.25	-	ASTM
G-3	8-1/2	0.10	3/8	SDHI
G-4	8-3/4	0.10	5/8	SDHI
G-5	9-3/8	0.25	1	ASTM
G-6	7	0.25	1	SDHI
G-7	7-1/4	0.10	1	ASTM
G-8	8	0.10	-	ASTM

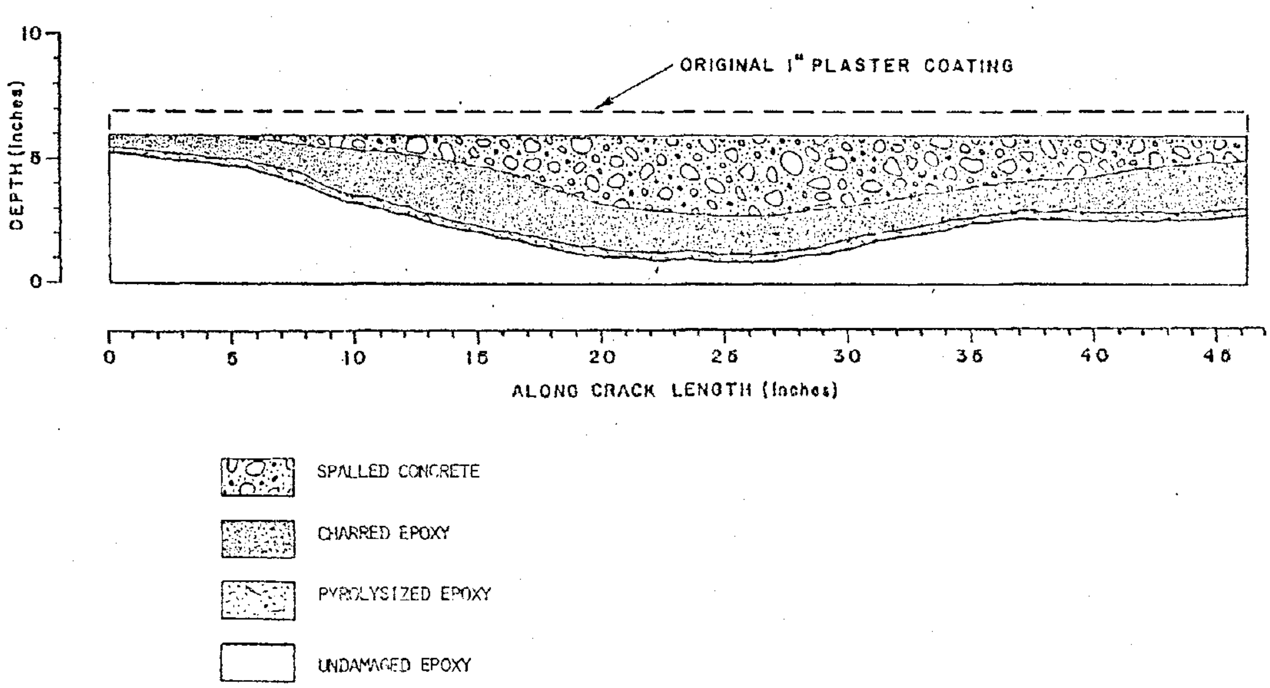
*THIS DIMENSION INCLUDES THE THICKNESS OF THE PLASTER COATING.

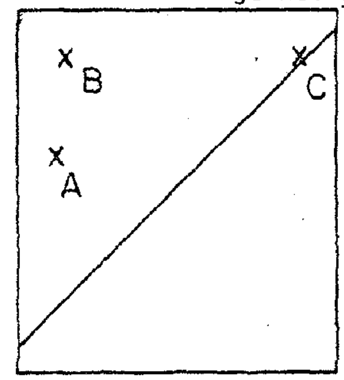
SEC. L.2.0: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-1

Specimen Thickness:	7 in. overall
Plaster Coating:	1 in.
Crack Width:	0.05 in.
Applied Load:	45 kips
Date of Test:	December 5, 1979
Time-Temperature Fire Curve:	ASTM (2-Hour)
% Error in Observed Time-Temperature Curve:	+0.10
Moisture Content of Plaster at; Surface:	5.69%
Mid-depth:	2.13%
Maximum Temperature On Unexposed Face:	93°C
Time of Failure:	No drop in load observed

CROSS SECTION OF CRACK

WALL G-1





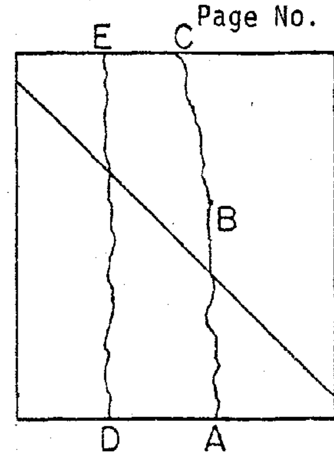
EXPOSED FACE

LONG BEACH STATE
GS-26943

OBSERVER J. ZICHERMAN

WALL G-1
12/5/79

TIME		OBSERVATIONS
MIN	SEC	
	00	START OF TEST.
4	10	FINISH PLASTER BEGINS TO SPALL.
8	50	75% OF FINISH PLASTER SPALLING.
12	00	ODOR OF BURNING EPOXY VERY DOMINANT.
12	20	DAMPER OPENED 1 ADDITIONAL LINK.
17	20	THERE IS NO VISIBLE FLAMING ON SPECIMEN AT THIS POINT.
21	57	FIRST INTERMITTENT FLAMING ON SPECIMEN SURFACE AT POINT "A" BEGINS.
22	30	THERE IS STEADY FLAMING AT POINT "B" AND POINT "C".
26	26	A HOLE IS DEVELOPING IN THE BASE PLASTER AT "A" ~4" DIAMETER.
31	30	A HOLE IS DEVELOPING IN THE BASE PLASTER AT "B" ~4" DIAMTER.
36	12	HOLE AT "A" REMAINING CONSTANT, HOLE AT "B" INCREASING, FLAMING
		CONTINUES.
44	22	HOLE AT "B" ENLARGING SLIGHTLY.
47	55	1ST SPALLING OCCURS (EXPLOSIVE) OF BASE COAT AND CONCRETE.
49	30	50% OF THE PLASTER BASE COAT IS GONE. UPPER LEFT HALF WITH LOWER
		RIGHT (ON A DIAGONAL) SECTION INTACT.
52	00	THERE IS A HOLLOW AREA AT LEAST 3" DEEP IN AREA DESCRIBED ABOVE.
53	15	LOWER RIGHT SECTION OF SPECIMEN GONE AS ABOVE.
55	30	EXPLOSIVE SPALLING CONTINUES; THERE IS A DIFFUSION FLAME ALONG REPAIR
		SEAM



UNEXPOSED FACE

OBSERVER J. ZICHERMAN

WALL G-1
CONTINUED

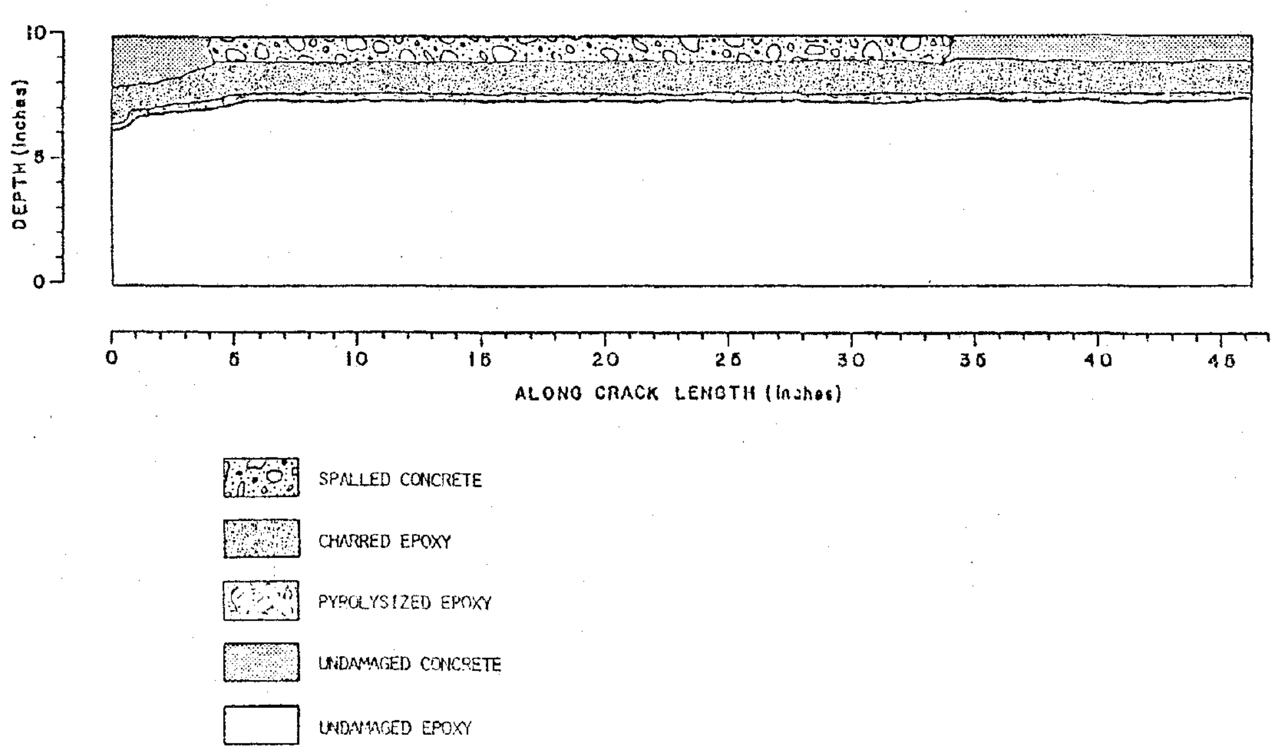
TIME		OBSERVATIONS
MIN	SEC	
64	00	NO CHANGE.
64	15	A CRACK HAS DEVELOPED IN REAR FACE AT "AB". WATER IS DRIPPING
		STEADILY FROM BACK FACE NEAR AND ABOVE CRACK "AB".
69	30	SPALLING DECREASES.
80	00	A VERTICAL CRACK APPEARS AT "ABC".
94	20	THERE IS A SLIGHT VISIBLE DISPLACEMENT IN BACK FACE AND SLIGHT
		DROP IN LOAD.
118	26	THE LOAD IS INCREASING SLIGHTLY. A CRACK HAS FORMED AT "DE". FLAMING
		CONTINUES AT REPAIR LINE.
120	00	FURNACE OFF - END OF TEST.

SEC. L.2.1: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-2

Specimen Thickness:	10 in. overall
Plaster Coating:	None
Crack Width:	0.25 in.
Applied Load:	45 kips
Date of Test:	November 27, 1979
Time-Temperature Fire Curve:	ASTM (2-Hour)
% Error in Observed Time-Temperature Curve:	+0.22
Moisture Content of Plaster at; Surface:	-
Mid-depth:	-
Maximum Temperature on Unexposed Face:	35°C
Time of Failure:	Wall began to yield after it was removed from furnace at 133 minutes, 15 seconds from start of test.

CROSS SECTION OF CRACK

WALL G-2



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11/27/79

WALL G-2

OBSERVER D. HEATHERINGTON

TIME		OBSERVATIONS
MIN	SEC	
	00	START OF TEST.
	50	IGNITION OF EPOXY.
1	50	EPOXY CAN BE SEEN RUNNING OUT OF THE CRACK. SPARKS ARE SHOOTING FROM
		THE CRACK.
2	30	FLAMING HAS CEASED EXCEPT FOR THE LOWER LEFT HAND CORNER OF THE CRACK.
3	40	FLAMES ARE TRAVELING ~2' UP THE CRACK.
4	30	FLAMES HAVE EXTENDED UP THE ENTIRE LENGTH OF THE CRACK.
5	15	THE EPOXY HAS RUN DOWN ~3"-6" ALONG THE CRACK. FLAMES ARE ~1' IN LENGTH
8	53	1ST SPALLING OCCURS AT UPPER RIGHT PORTION OF CRACK.
12	30	NO CHANGE.
12	50	2ND SPALLING OF CONCRETE OCCURS AT UPPER RIGHT.
13	50	THERE IS SPALLING OF CONCRETE IN THE MIDDLE OF THE CRACK LENGTH.
15	20	THE UNEXPOSED FACE OF THE SPECIMEN HAS SOME MOISTURE DRIPPING DOWN IT.
19	30	FLAMES CONTINUE TO COME OUT OF THE CONCRETE WHERE IT HAS SPALLED AWAY
		ALONG THE CRACK.
30	00	NO CHANGE.
40	00	NO CHANGE. THERE IS NO EPOXY LEFT EXPOSED IN THE CRACK LENGTH.
50	00	NO CHANGE.
60	00	FLAMING APPEARS ONLY WHERE THE CONCRETE HAS SPALLED AWAY FROM THE CRACK
		AND THE BOTTOM LEFT CORNER.

OBSERVER D. HEATHERINGTON

WALL G-2

CONTINUED

TIME		OBSERVATIONS
MIN	SEC	
70	00	FLAMING IN CRACK HAS DIMINISHED TO ~6".
80	00	NO CHANGE.
90	00	THE UNEXPOSED FACE STILL HAS A LITTLE MOISTURE ON IT.
100	00	NO CHANGE.
105	00	A HAIRLINE CRACK HAS FORMED ON THE UNEXPOSED FACE AND MOISTURE IS
		DRIPPING OUT OF IT.
110	00	NO CHANGE.
115	00	NO CHANGE.
120	00	END OF TEST WITHOUT FAILURE
133	15	FIRST SIGN WALL STARTED TO YIELD.

SEC. L.2.2: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-3

Specimen Thickness:	8-1/2 in. overall
Plaster Coating:	3/8 in.
Crack Width:	0.10 in.
Applied Load:	45 kips
Date of Test:	December 4, 1979
Time-Temperature Fire Curve:	SDHI (1-Hour)
% Error in Observed Time-Temperature Curve:	+0.04
Moisture Content of Plaster at; Surface:	12.43%
Mid-depth:	2.08%
Maximum Temperature on Unexposed Face:	17°C
Time of Failure:	No failure after 1 hour.

NOTE: The specimen could not be broken open along the epoxy repaired crack so no cross-section is available.

OBSERVER J. ZICHERMAN

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WALL G-3
12/4/79

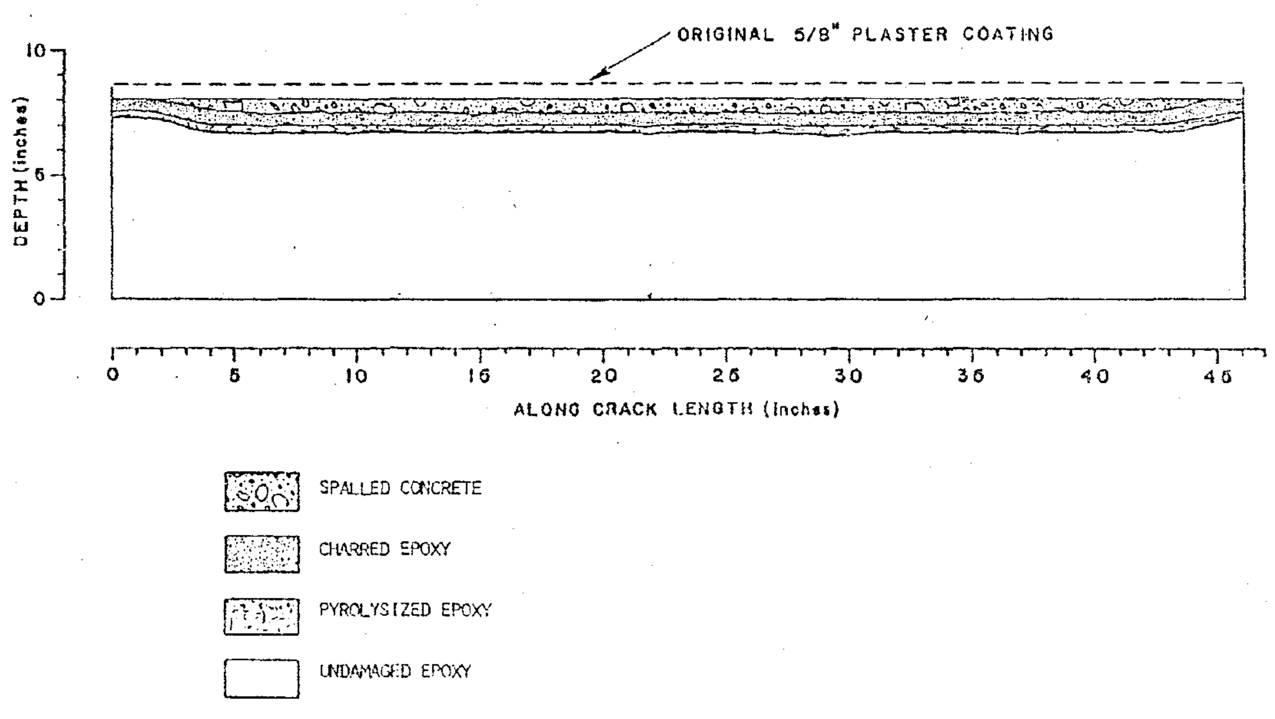
TIME		OBSERVATIONS
MIN	SEC	
	00	FURNACE ON.
6	20	INTERMITTENT FLAMING AT LOWER EDGE OF SPECIMEN.
8	10	INTERMITTENT FLAMING OVER SPECIMEN SURFACE.
8	56	MOST OF THE FINISH PLASTER HAS COME OFF; SMALL BRANDS ARE DECENDING
		INTO FURNACE.
10	20	PLASTER BASE IN PANEL CENTER IS ABLATED, THERE IS GENERAL FLAMING
		CONTINUING AS AT 8 MIN/10 SEC.
11	05	EXPLOSIVE SPALLING BEGINS.
11	45	EXPLOSIVE SPALLING CONTINUES.
12	00	TOP ROW OF BURNERS IS TURNED OFF.
13	17	EXPLOSIVE SPALLING CONTINUES.
15	00	EVERY 2ND BURNER IN NEXT ROW (2ND FROM TOP) IS TURNED OFF.
15	50	ALL BURNERS IN 2ND ROW FROM THE TOP ARE TURNED OFF.
15	55	SURFACE FLAMING BEGINS ON SPECIMEN ONLY AT LOWER LEFT AND UPPER RIGHT.
16	50	ALL 2ND AND 3RD TOW BURNERS (FROM TOP) TURNED OFF.
20	00	FURNACE DARKENING; VISION OBSCURRED.
24	00	ALL 5TH ROW BURNERS OFF.
31	30	FRAME UNBOLTED.
35	50	END BURNERS OFF - LOWER ROW.
60	00	FURNACE OFF. END OF TEST.

SEC. L.2.3: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-4

Specimen Thickness:	8-3/4 in. overall
Plaster Coating:	5/8 in.
Crack Width:	0.10 in.
Applied Load:	45 kips
Date of Test:	November 30, 1979
Time-Temperature Fire Curve:	SDHI (1-Hour)
% Error in Observed Time-Temperature Curve:	-1.00
Moisture Content of Plaster at; Surface:	10.90%
Mid-depth:	2.13%
Maximum Temperature on Unexposed Face:	20°C
Time of Failure:	No failure after 1 hour.

CROSS SECTION OF CRACK

WALL G-4



LONG BEACH STATE
GS-26943
11/30/79
WALL G-4

OBSERVER J. ZICHERMAN

TIME		OBSERVATIONS
MIN	SEC	
	00	START OF TEST.
3	30	NO CHANGE.
6	40	PROTECTIVE MESH GLOWING RED, FINISH PLASTER IS SPALLING.
7	40	THERE IS ADDITIONAL FINISH PLASTER SPALLING.
8	50	FLAMING BEGINS AT SPECIMEN BOTTOM.
10	20	THERE IS EXPLOSIVE SPALLING.
11	00	EXPLOSIVE SPALLING CONTINUES.
11	50	CHUNKS OF CONCRETE COMING OFF OF SPECIMEN.
12	00	TOP ROW OF BURNERS ARE TURNED OFF.
12	20	BIGGER CHUNKS OF CONCRETE ARE COMING OFF - EXPLOSIVE NOISES.
15	00	SPALLING STOPS, SMALL FLAMES BEGIN AT REPAIR JOINT.
16	00	NO FURTHER FLAMING AT REPAIR JOINT.
17	50	UNABLE TO OBSERVE SAMPLE AS IT IS SOMEWHAT OBSCURED BY KAOWOOL FLAP.
26	15	NO CHANGE.
31	00	TEST FRAME OPENED.
55	00	NO CHANGE.
60	00	END OF TEST.

SEC. L.2.4: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-5

Specimen Thickness:	9-3/8 in.
Plaster Coating:	1 in.
Crack Width:	0.25 in.
Applied Load:	45 kips
Date of Test:	November 28, 1979
Time-Temperature Fire Curve:	ASTM (2-Hour)
% Error in Observed Time-Temperature Curve:	+0.08
Moisture Content of Plaster at; Surface:	9.58%
Mid-depth:	2.09%
Maximum Temperature on Unexposed Face:	25°C
Time of Failure:	Load began to drop off after the specimen was removed from the furnace at 136 minutes, 35 seconds from start of test.

CROSS SECTION OF CRACK

WALL G-5

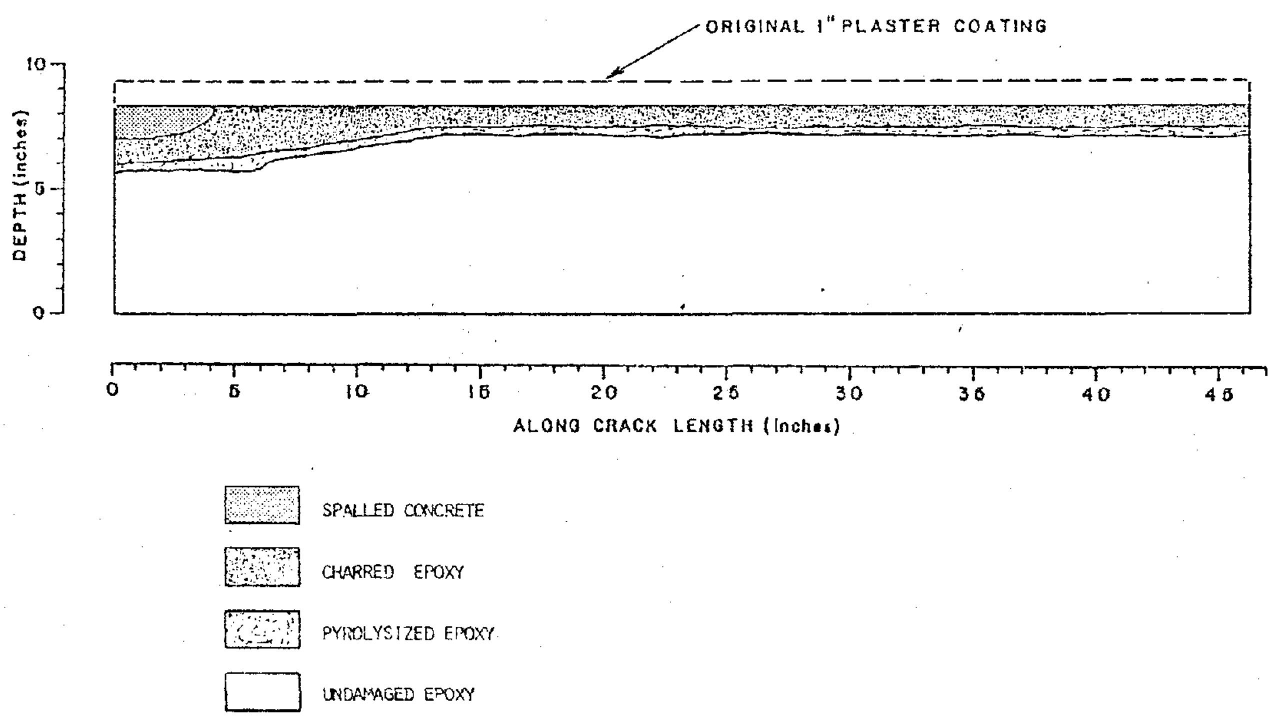
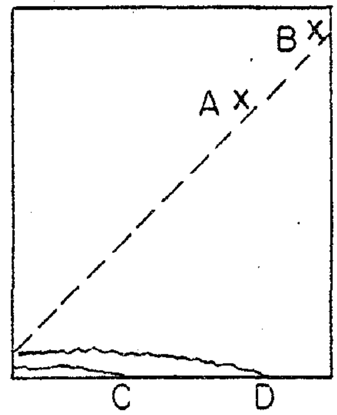


FIGURE 1



EXPOSED FACE

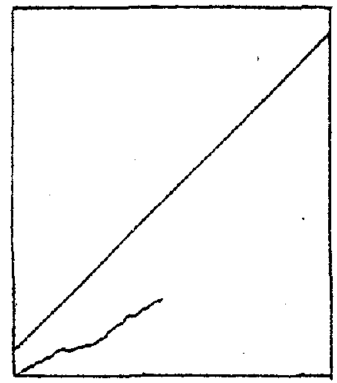
LONG BEACH STATE
GS-26943

OBSERVER J. ZICHERMAN

11/28/79

WALL G-5

TIME MIN	TIME SEC	OBSERVATIONS
	45	FINISH PLASTER IS CRACKING.
1	05	FINISH PLASTER IS PARTIALLY SPALLING (60% OFF).
2	11	FINISH PLASTER IS SPALLING FURTHER.
5	00	FINISH PLASTER IS SPALLING FURTHER, ~80% IS GONE.
10	30	NO FURTHER CHANGE.
18	30	NO CHANGE.
21	40	WHITE AREA IN GRAY FIELD APPEARS AT "A" (FIG. 1).
22	55	IGNITION BEGINS AT "A".
24	30	TRANSIENT FLAMING BEGINS AT "B".
25	04	FINISH PLASTER SPALLING CONTINUES.
25	40	FLAMING CONTINUES AT "B".
29	30	FLAMING CONTINUES TO "B" - HYPOTHESIS: FLAMMABLE GASES ARE EXITING AT
		SPECIMEN EDGE BEHIND FACE PLASTER.
33	09	FLAMING AT "B" INCREASES.
34	55	FLAMING BEGINS AT "D".
36	05	FLAMING BEGINS AT "C".
37	10	FLAMING INCREASES AT "C".
38	12	FLAMING ALONG SPECIMEN BOTTOM (C-D) INCREASING.
40	00	SPALLING OF PLASTER BASE (~2$''^2$) AT "B".
45	00	NO EFFECTS ON SPECIMEN BACK FACE.



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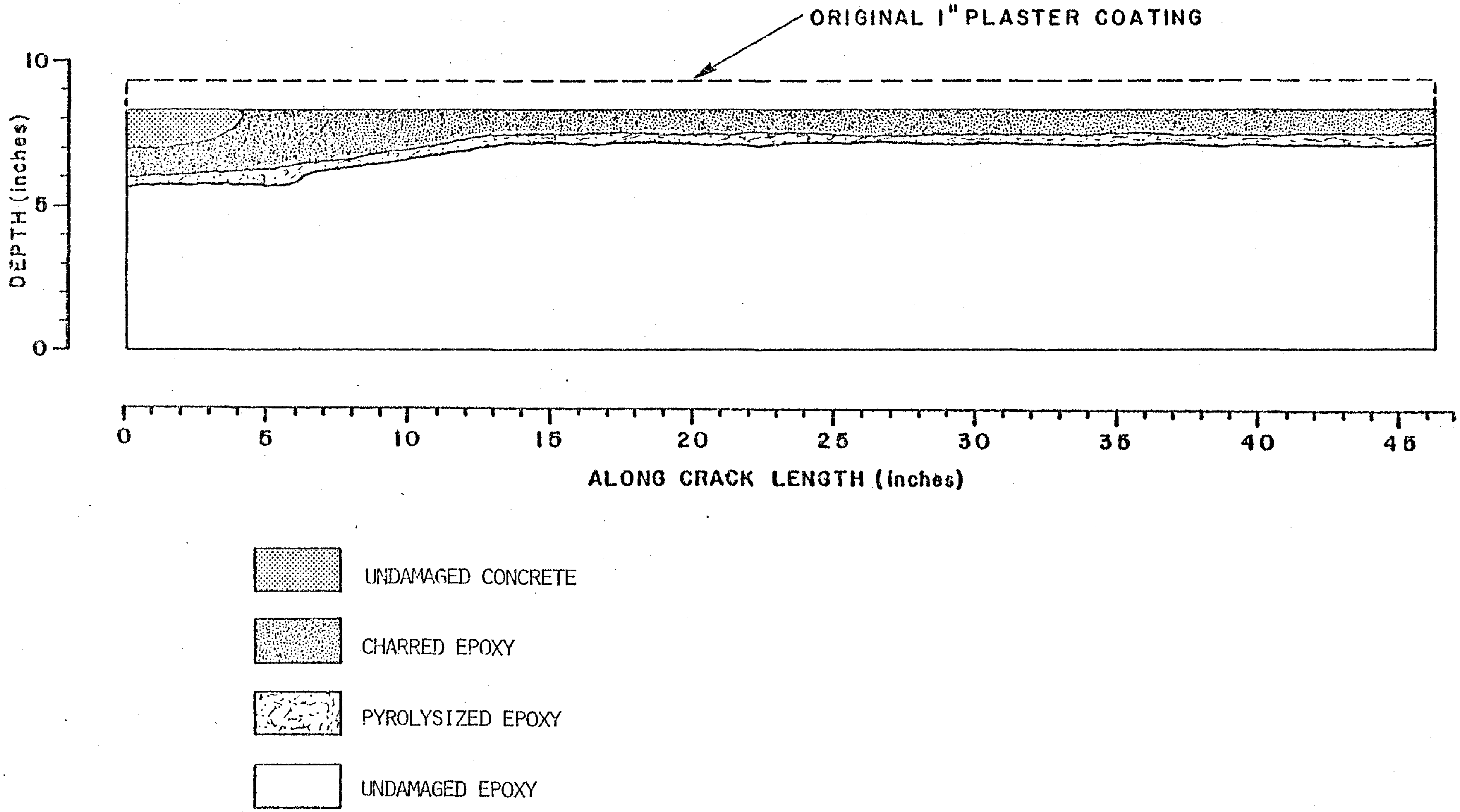
WALL G-5
CONTINUED

EXPOSED FACE

TIME		OBSERVATIONS
MIN	SEC	
52	50	SPALLED AREA INCREASE TO 4-8"^{2} AT "B".
62	18	GENERAL FLAMING AT "C-D" CONTINUES.
72	00	NO CHANGE.
83	00	NO CHANGE.
90	00	SOME BUCKLING OF PLASTER BARE COAT BUT BASE COAT REMAINS INTACT ON
		SPECIMEN.
105	00	FLAMING CONTINUES AT REDUCED LEVEL AT SPECIMEN BOTTOM AND UPPER RIGHT.
112	10	SMALL CRACK HAS FORMED (FIG 2) IN PLASTER BARE COAT. DOES NOT EMIT
		FLAMES.
117	00	NO CHANGE.
120	00	FURNACE OFF.
122	20	ADDITIONAL FALL OFF AT "B" (FIG. 1) ON REMOVAL OF SPECIMEN FROM FURNACE.
128	20	SUBSTANTIAL PLASTER FALL-OFF.
136	35	LOAD DROPPING OFF SLOWLY - ≃ 80.16".
140	50	LOADING DROPPING OFF CONTINUES.
142	05	LOAD RELEASED - END OF TEST.

CROSS SECTION OF CRACK

WALL G-5

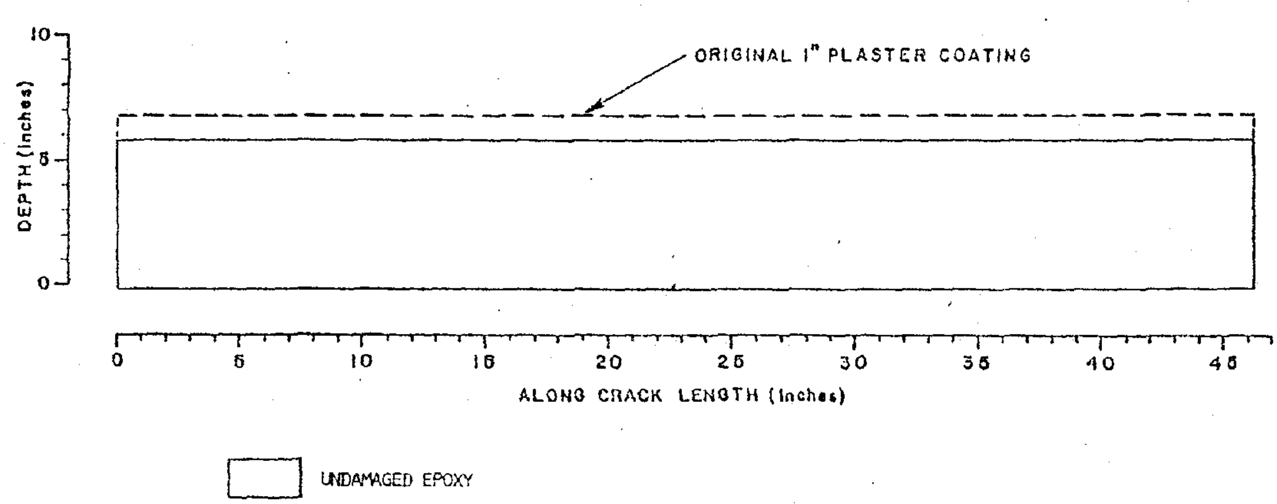


SEC. L.2.5: EXPERIMENTAL TESTS RESULTS OF SPECIMEN G-6

Specimen Thickness:	7 in. overall
Plaster Coating:	1 in.
Crack Width:	0.25 in.
Applied Load:	45 kips
Date of Test:	December 3, 1979
Time-Temperature Fire Curve:	SDHI (1-Hour)
% Error in Observed Time-Temperature Curve:	-0.53
Moisture Content of Plaster at; Surface:	9.51%
Mid-depth:	2.18%
Maximum Temperature on Unexposed Face:	19°C
Time of Failure:	No drop in load after 1 hour.

CROSS SECTION OF CRACK

WALL G-6



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WALL G-6
12/3/79

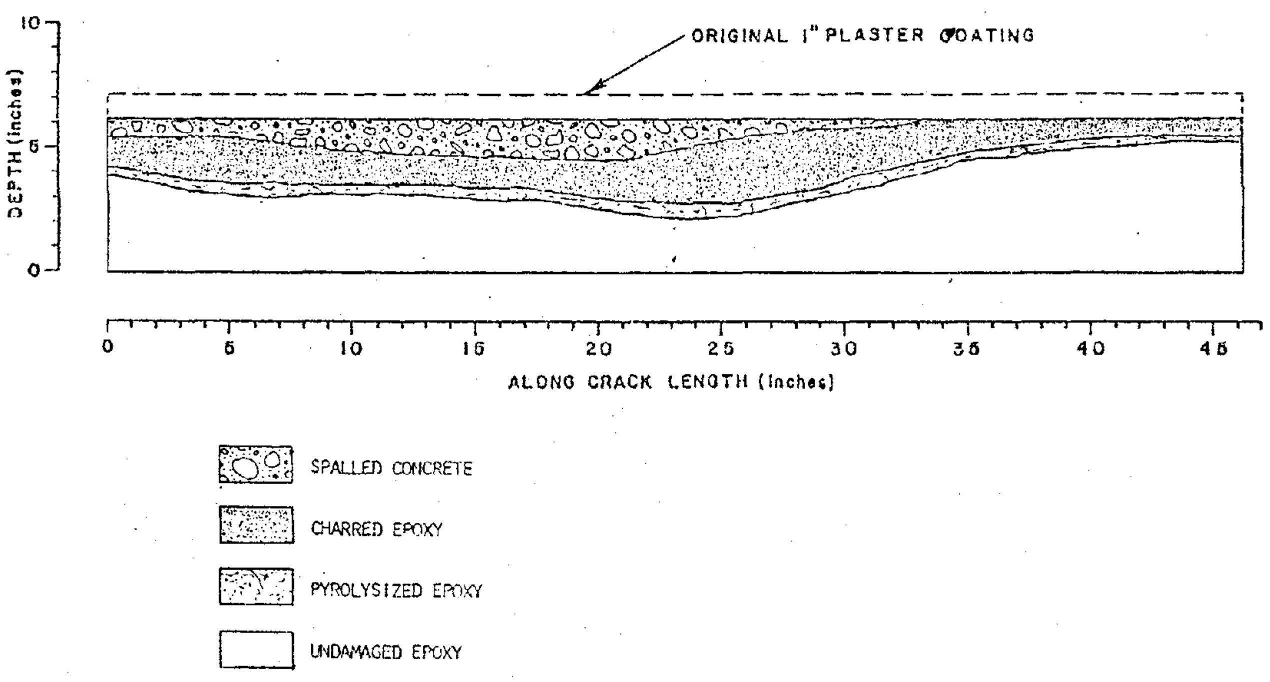
TIME MIN	TIME SEC	OBSERVATIONS
	00	START OF TEST.
2	00	NO CHANGE.
5	10	PLASTER TOPCOAT GOING.
6	19	WIRE MESH IS GLOWING RED.
8	10	ALL FINISH (TOPCOAT) PLASTER IS OFF.
9	40	DAMPERS OPENED TO GREEN POSITION.
12	00	TOP ROW OF BURNERS IS TURNED OFF.
16	00	DAMPERS OPENED FULLY.
16	30	FURNACE DARKENING; VISION OBSCURED BY DARKNESS.
26	17	ALL BURNERS OFF EXCEPT 6 ON BOTTOM ROW.
32	00	FRAME UNBOLTED, 4 BURNERS STILL ON.
45	00	NO CHANGE.
60	00	NO CHANGE, FURNACE OFF.
		POST TEST - FACE PLASTER ALL OFF
		BASE PLASTER 80% INTACT, ABLATED AT LOWER EDGE AROUND HOOKS.
		SMALL CRACK AT LOWER LEFT TO UPPER RIGHT.

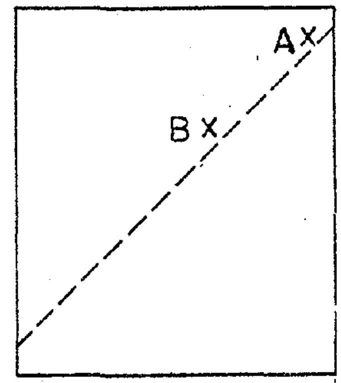
SEC. L.2.6: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-7

Specimen Thickness:	7-1/4 in.
Plaster Coating:	1 in.
Crack Width:	0.10 in.
Applied Load:	45 kips
Date of Test:	December 7, 1979
Time-Temperature Fire Curve:	ASTM (2-Hour)
% Error in Observed Time-Temperature Curve:	-0.14
Moisture Content of Plaster at; Surface:	10.40%
Mid-depth:	1.95%
Maximum Temperature on Unexposed Face:	104°C
Time of Failure:	1 hour, 18 minutes, 40 seconds.

CROSS SECTION OF CRACK

WALL G-7





EXPOSED FACE

OBSERVER J. ZICHERMAN

LONG BEACH STATE
GS-26943

WALL G-7
12/7/79

TIME		OBSERVATIONS
MIN	SEC	
	00	START OF TEST.
1	18	FINISH PLASTER SPALLED.
9	00	NO CHANGE.
12	40	NO CHANGE.
28	05	NO CHANGE.
33	05	1ST INTERMITTENT FLAMING OCCURS ON THE SPECIMEN SURFACE AT POINTS
		"A" AND "B".
35	33	A HOLE IF FORMING AT "A" (~3" IN DIAMETER).
39	04	THE HOLE AT "A" IS ENLARGING, "B" IS STILL BURNING STEADILY.
39	15	THE BASE PLASTER BETWEEN "A" AND "B" HAS COME OFF PRODUCING AN OVAL
		HOLE.
40	48	THERE IS EXTENSIVE FLAMING AT THE HOLE SINCE IT OPENED.
41	02	1ST EXPLOSIVE SPALLING OCCURS.
45	12	THE BASE PLASTER OF THE UPPER RIGHT (25%) OF THE WALL HAS COME OFF.
50	56	THE BASE PLASTER OF 50% OF THE SPECIMEN IS OFF.
52	50	A VERTICAL CRACK HAS FORMED DOWN THE BENTER OF THE SPECIMEN (BACKFACE)
		DIAGONALLY TO THE EPOXY REPAIR CRACK.
55	00	EXPLOSIVE SPALLING HAS STOPPED. 50% OF THE BASE PLASTER REMAINS.
70	10	UPPER LEFT OF SPECIMEN BACK HAS CRACKED; SLIGHT LOAD DROP-OFF. SEVERAL
		OTHER CRACKS HAVE APPEARED AS WELL.

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WALL G-7
CONTINUED

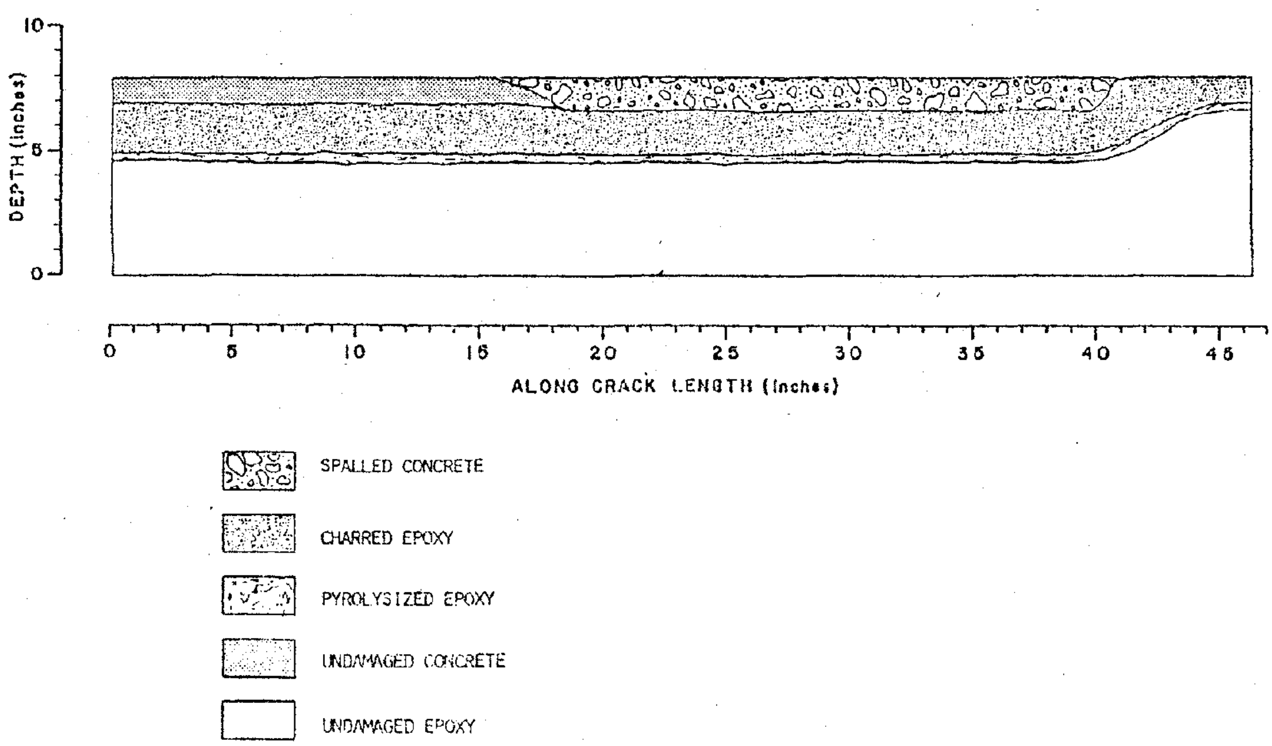
TIME MIN	TIME SEC	OBSERVATIONS
78	40	LOAD CONTINUES TO DROP OFF; STRUCTURAL FAILURE.
86	10	NO CHANGE.
97	20	REPAIR SEAM STILL FLAMING; NO OTHER CHANGES.
110	00	NO FURTHER CHANGES.
116	00	CRACKS APPEAR IN BACK FACE.
120	00	END OF TEST.

SEC. L.2.7: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-8

Specimen Thickness:	8 in. overall
Plaster Coating:	none
Crack Width:	0.10 in.
Applied Load:	45 kips
Date of Test:	November 20, 1979
Time-Temperature Fire Curve:	ASTM (2-Hour)
% Error in Observed Time-Temperature Curve:	+0.16
Moisture Content of Plaster at; Surface:	-
Mid-depth:	-
Maximum Temperature on Unexposed Face:	N.A.
Time of Failure:	No drop in load after 2 hours.

CROSS SECTION OF CRACK

WALL G-8



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11/20/79

OBSERVER D. HEATHERINGTON

WALL G-8

TIME		OBSERVATIONS
MIN	SEC	
	00	START OF TEST.
1	40	THE EPOXY IS FLAMING AND IS CONCENTRATED AT BOTTOM LEFT CORNER.
3	20	~8" FLAMES ARE COMING FROM THE ENTIRE CRACK.
4	20	NO CHANGE.
6	03	THERE ARE FLAMES OF 2'.
7	02	SOME OF THE EPOXY IS FALLING OUT OF THE CRACK.
9	10	THE OUTER LAYER OF THE EPOXY CONTINUES TO POP OFF IN A SHOWER OF SPARKS.
11	55	A LARGE PIECE OF CONCRETE SPALLED OFF OF THE EXPOSED FACE ALONG THE
		CRACK LINE.
12	30	THE LOWER HALF OF THE SPECIMEN IS COMPLETELY CHARRED.
16	00	MOST OF THE FLAMING FROM THE CRACK HAS STOPPED.
17	00	THE CONCRETE AROUND THE CRACK HAS ALL SPALLED OFF.
19	00	SPARKS CONTINUE TO COME DOWN FROM THE EPOXY WHICH IS CHARRING AWAY.
22	00	THE CONCRETE APPEARS TO HAVE SPALLED OFF TO A DEPTH OF ~1.5"-2".
25	00	FLAMES OF ~2"-3" CONTINUE TO BE SEEN AT SPOTS ALONG THE CRACK.
30	00	NO CHANGE.
35	10	NO CHANGE.
44	30	THERE ARE COME FLAMES COMING FROM THE CERAMIC FIBER COVERING THE LEFT
		CORNER OF THE CRACK.
50	00	NO CHANGE.

OBSERVER D. HEATHERINGTON

WALL G-8
CONTINUED

TIME		OBSERVATIONS
MIN	SEC	
60	00	NO CHANGE.
70	00	NO CHANGE.
80	00	MOISTURE HAS APPEARED ON THE BACK FACE.
90	00	NO CHANGE.
100	00	NO CHANGE.
110	00	NO CHANGE.
120	00	END OF TEST WITHOUT FAILURE.

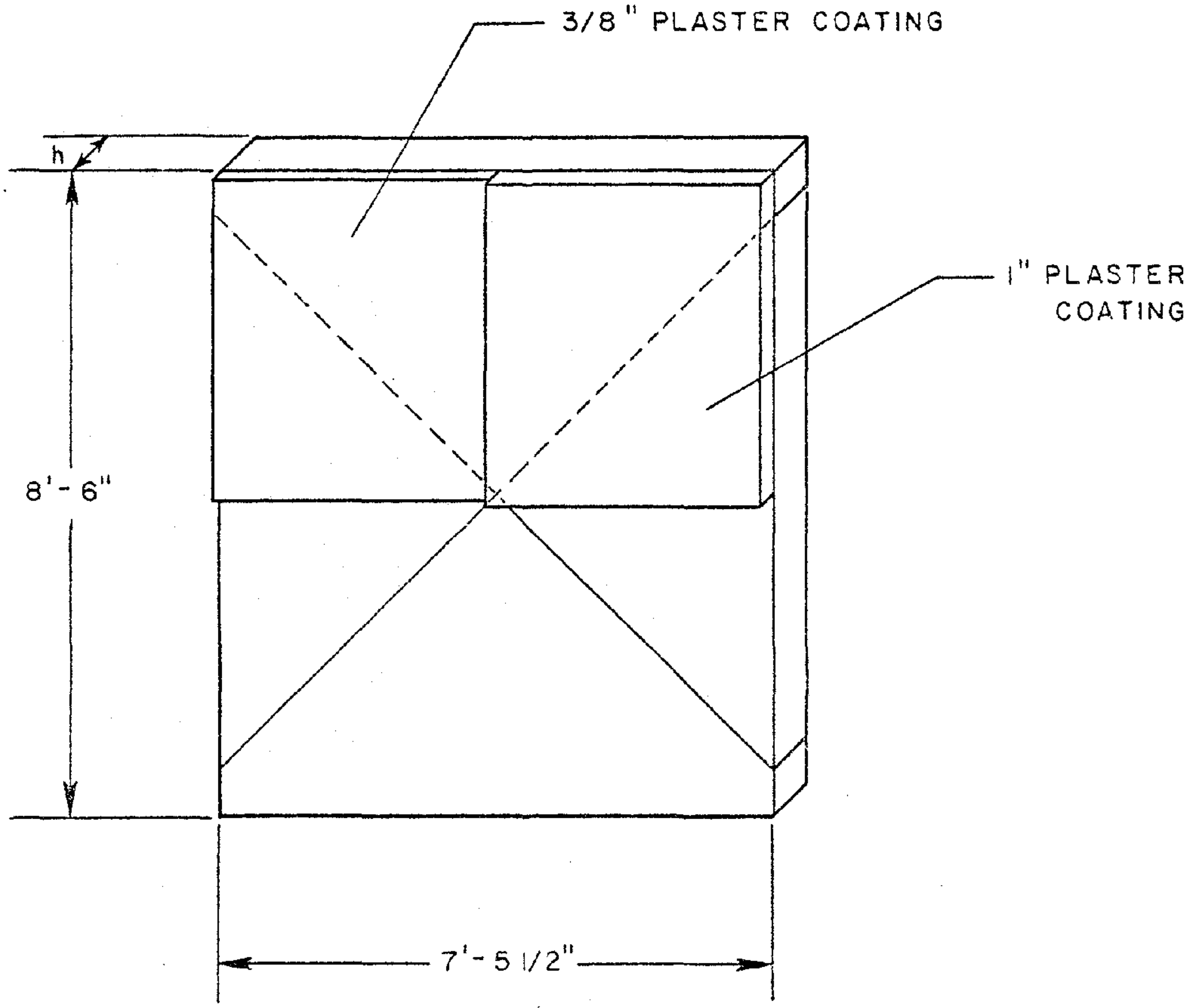
CHAPTER M: EXPERIMENTAL TEST RESULTS OF LARGE-SCALE SPECIMENS

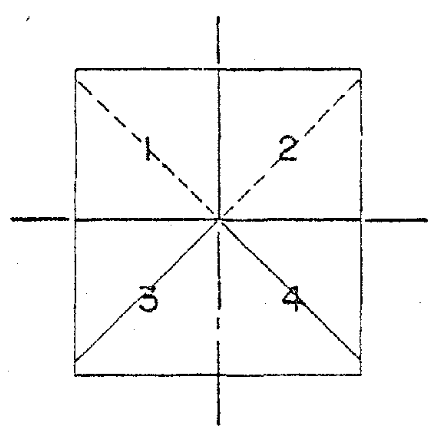
SEC. M.1.0: INTRODUCTION

This chapter contains the experimental test results obtained from fire tests on two large-scale epoxy repaired shear wall specimens of the dimensions shown in Figure M-1. These tests were conducted at the University of California, Richmond Field Station, Fire Test Laboratory on December 17 and December 21, 1979. The Test apparatus and procedure used in carrying out these tests is described in section K.3.1 and section K.3.2, respectfully.

The remainder of this chapter is sectioned according to the results obtained from each experiment. Each section contains a description of the specimen before the test and the conditions under which it was tested. Also contained in the results is a log of visual observations taken during the experiment and a sketch of the epoxy repaired crack for each quadrant after the test was completed.

LARGE-SCALE WALL SPECIMENS





SPECIMEN G-9 ; h=6"
SPECIMEN G-10; h=8"

FIGURE M-1

SEC. M.2.0: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-9

Specimen Thickness: 6 in.

Crack Width: Quadrant 1 = 0.1"; Quadrant 2-4= 0.25"

Applied Load: 60 kips

Date of Test: December 17, 1979

Time-Temperature Fire Durve: ASTM (2-Hour)

% Error in Observed Time-Temperature Curve: -0.02

Quadrant	Plaster Coating, in.	% Moisture Content	
		Surface	Mid-depth
1	3/8	12.18	2.16
2	1	9.51	2.26

Maximum Temperature on Unexposed Face: 88°C

Time of Failure: 50 minutes

NOTE: The crack in Quadrant 3 was covered by a 4" wide, 1/8" thickness of fire resistant epoxy foam.

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WALL G-9
12/17/79

TIME		OBSERVATIONS
MIN	SEC	
	00	START OF TEST.
	25	THERE IS SOME FLAMING FROM COATING ON CRACK #3.
1	30	THE PLASTER HAS FALLEN OFF OF BOTH TOP PANELS. FLAMES APPROXIMATELY
		4' LONG ARE COMING OFF CRACK #3 WITH SMALL, 6" FLAMES COMING OFF #4.
3	10	FLAMES FROM CRACK #3 ARE CONCENTRATED ALONG THE BOTTOM HAVE OF THE
		CRACK.
4	30	FLAMES HAVE APPEARED ALONG CRACKS #1 AND #2 WHERE THE PLASTER HAS
		FALLEN OFF.
5	30	THE PLASTER COATING OVER CRACK #1 HAS COMPLETELY FALLEN AWAY.
8	00	FLAMES ARE COMING OFF OF ALL EXPOSED EPOXY LINES.
9	30	SPALLING IS OCCURRING ALONG CRACK #2 AND #4.
12	00	SPALLING IS OCCURRING RAPIDLY OVER THE ENTIRE SURFACE OF THE SPECIMEN.
15	00	SPALLING CONTINUES WITH FLAMES COMING OFF OF ALL FOUR EPOXY LINES.
18	00	THE ONLY REMAINING PLASTER IS IN THE UPPER RIGHT HAND CORNER OF #2.
18	30	WATER IS RUNNING OUT OF A CRACK WHICH IS LOCATED AT ABOUT THE 6' LEVEL
		IN THE MIDDLE OF THE WALL.
20	00	A CRACK HAS DEVELOPED ON THE BACK FACE WHICH EXTENDS FROM THE 6'
		LEVEL TO THE BOTTOM IN THE MIDDLE OF THE WALL.
22	00	SPALLING CONTINUES BUT AT A SLOWER RATE.
27	00	MOISTURE IS RUNNING OUT FROM SEVERAL PLACES ON THE UNEXPOSED SIDE.

WALL G-9
CONTINUED

TIME		OBSERVATIONS
MIN	SEC	
		WATER VAPOR CAN ALSO BE SEEN ESCAPING.
35	00	SPALLING HAS ALMOST CEASED.
40	00	THE REMAINING PLASTER ON #2 FELL OFF.
44	00	~65% OF #1 HAS SPALLED AWAY.
		~60% OF #2 HAS SPALLED AWAY.
		~50% OF #4 HAS SPALLED AWAY.
		~35% OF #3 HAS SPALLED AWAY.
53	00	THE CRACK ON THE BACK FACE HAS WIDENED.
55	00	HYDRAULIC PRESSURE IS DROPPING OFF. A SEPARATION BETWEEN THE EPOXY
		AND THE CONCRETE HAS OCCURRED ALONG CRACK #4. LOAD LOWERED TO 2,250
		PSI.
57	00	SPALLING HAS CEASED.
72	00	THE SPECIMEN HAS COMPLETELY COME APART ALONG EPOXY LINE #4.
85	00	NO CHANGE.
95	00	NO CHANGE.
105	00	FROM THE UNEXPOSED SIDE A LARGE BULGE IS NOTICEABLE IN THE MIDDLE OF
		THE WALL.
110	00	NO CHANGE.
115	00	NO CHANGE.
120	00	END OF TEST.

CROSS SECTION OF CRACK
WALL G-9

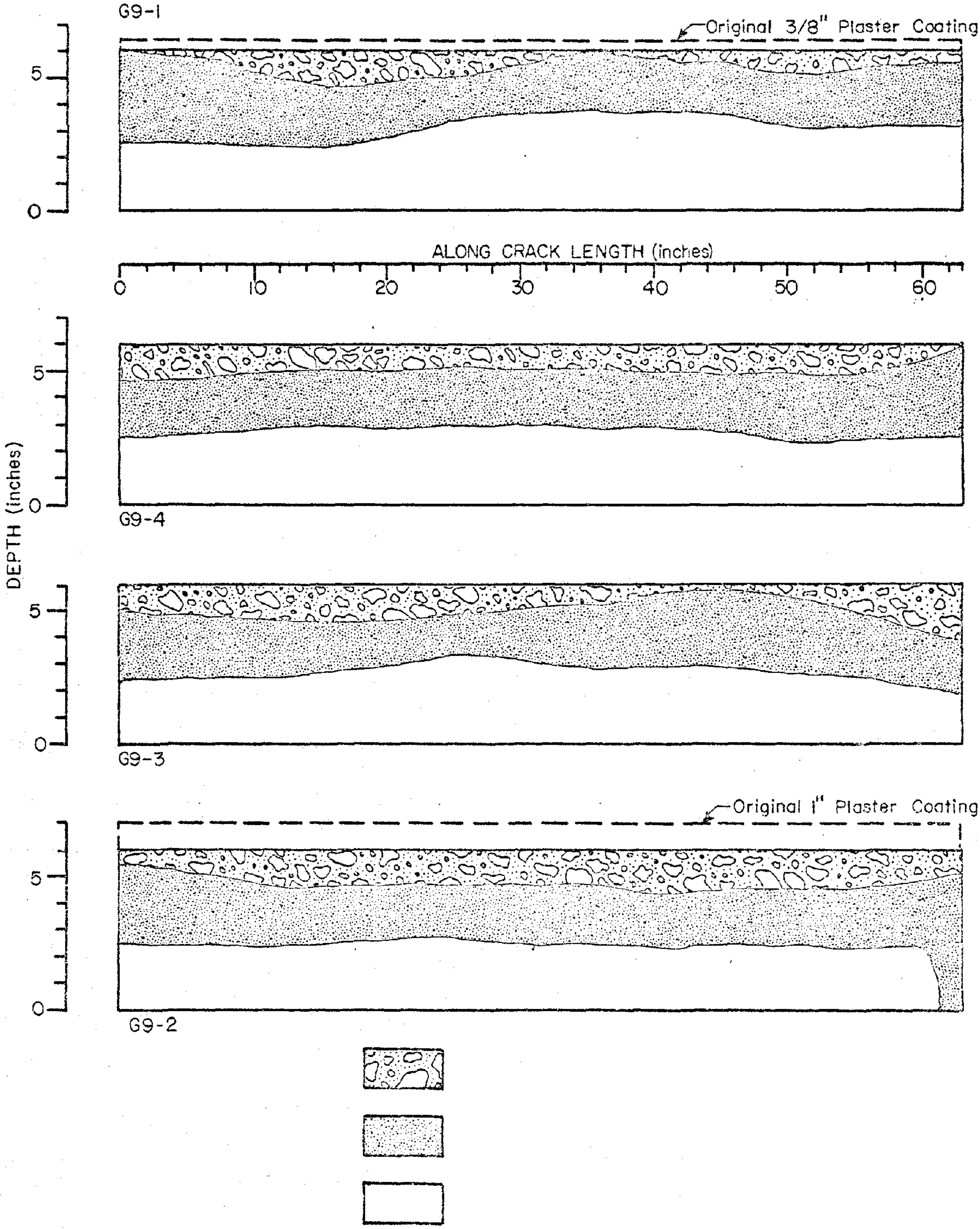

FIGURE M-2

SEC. M.2.1: EXPERIMENTAL TEST RESULTS OF SPECIMEN G-10

Specimen Thickness: 8 in.

Crack Width: All cracks = 0.25"

Applied Load: 60 kips

Date of Test: December 21, 1979

Time-Temperature Fire Curve: ASTM (2-Hour)

% Error in Observed Time-Temperature Curve: -0.02

Quadrant	Plaster Coating, in.	% Moisture Content	
		Surface	Mid-depth
1	3/8	6.13	3.65
2	1	15.06	3.34

Maximum Temperature on Unexposed Face: 61°C

Time of Failure: 1 hour, 20 minutes

NOTE: The upper half of the crack in Quadrant 3 was coated with a 1/2" thickness of 4" wide fire resistant epoxy foam. The lower half of this crack was coated with a 1/2" thickness of calcium silicate.

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WALL G-10
12/21/79

TIME		OBSERVATIONS
MIN	SEC	
	00	START OF TEST.
	22	PLASTER IN QUADRANT 1 IS FALLING OFF.
	38	PLASTER IN QUADRANT 2 IS FALLING OFF.
1	20	ALL OF THE PLASTER IN QUADRANT 1 HAS FALLEN OFF.
1	40	FLAMES ARE COMING OFF OF THE EPOXY-REPAIRED CRACKS IN QUADRANTS 3 & 4.
3	00	FLAMES ARE COMING OFF FROM QUADRANT 3 ONLY.
3	30	NO FLAMING FROM ANYWHERE ON SPECIMEN.
4	00	FLAMING HAS RESUMED ON QUADRANTS 3 AND 4.
4	15	FLAMES HAVE APPEARED ON QUADRANT 1.
7	00	SOME SPALLING OCCURRING OVER Q-4
7	30	SPALLING HAS STARTED OVER Q-3
8	00	RAPID SPALLING IS OCCURRING OVER THE ENTIRE FACE OF THE SPECIMEN.
		THE SPALLING SEEMS TO BE CONCENTRATED ALONG THE EPOXY LINES.
10	00	MOST OF THE SPALLING IS OCCURRING IN QUADRANTS 3 AND 4
12	30	~65% OF THE SURFACE AREA IN Q-3 HAS SPALLED.
		~45% OF THE SURFACE AREA IN Q-4 HAS SPALLED.
		~35% OF THE SURFACE AREA IN Q-1 HAS SPALLED
		~15% OF THE SURFACE AREA IN Q-2 HAS SPALLED.
13	00	THE REMAINING PLASTER ON Q-2 HAS FALLEN OFF EXCEPT FOR A SMALL PATCH
		AROUND THE EXPOSED REBAR.

WALL G-10
CONTINUED

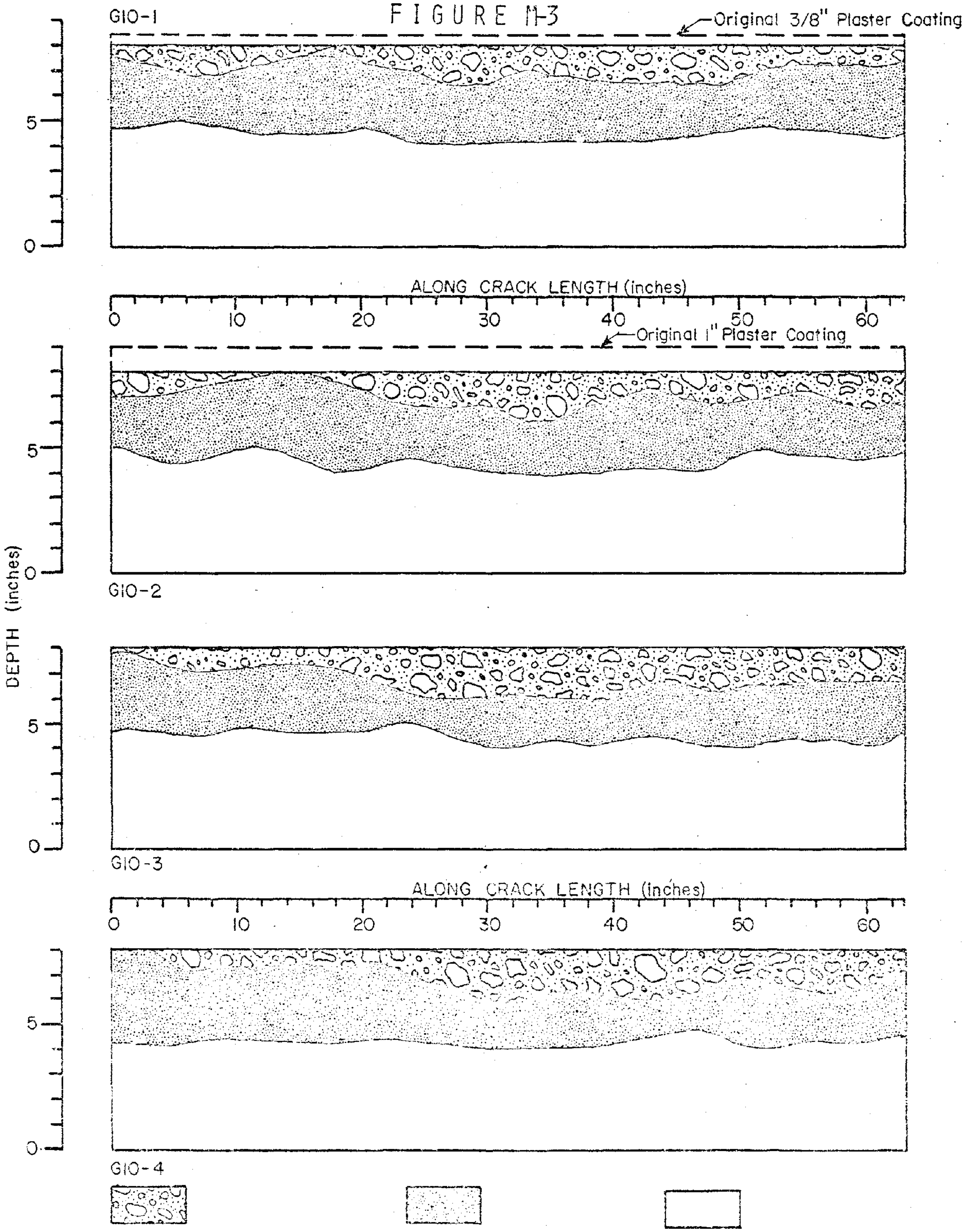
TIME		OBSERVATIONS
MIN	SEC	
15	00	FLAMES ARE COMING FROM ALL FOUR EPOXY SEAMS.
16	00	RAPID SPALLING CONTINUES OVER THE ENTIRE SPECIMEN.
19	00	~80% OF THE SURFACE AREA IN Q-3 HAS SPALLED
		~55% OF THE SURFACE AREA IN Q-4 HAS SPALLED.
		~50% OF THE SURFACE AREA IN Q-1 HAS SPALLED
		~35% OF THE SURFACE AREA IN Q-2 HAS SPALLED.
25	00	SPALLING HAS NEARLY STOPPED
29	00	THE EPOXY REPAIRED CRACK IN Q-4 HAS A FOAMING SUBSTANCE FLOWING FROM
		IT.
39	00	THE SUBSTANCE OOZING FROM EPOXY SEAM IN Q-4 HAS STOPPED. ALL SPALLING
		HAS CEASED. FLAMING CONTINUES FROM ALL FOUR EPOXY-REPAIRED CRACK.
43	00	TWO SMALL CRACKS HAVE FORMED ON THE UNEXPOSED FACE WITH STEAM
		EMANATING FROM THEN.
50	00	THE CRACKS NOTED AT 43 MINUTES HAVE EXTENDED IN LENGTH.
57	00	A SMALL CRACK NOW EXTENDS TO THE TOP OF THE SPECIMEN ON THE UNEX-
		POSED FACE. ALL FOUR CRACKS ARE STILL FLAMING.
65	00	NO CHANGE.
68	00	ANOTHER SMALL CRACK HAS FORMED ON THE UNEXPOSED FACE.
76	00	WATER IS BUBBLING OUT OF ALL OF THE CRACKS PREVIOUSLY NOTED.
80	40	FAILURE. HYDRAULIC PRESSURE DROPPED OFF WITH THE EPOXY LINES OPENING

WALL G-10
CONTINUED

TIME		OBSERVATIONS
MIN	SEC	
		UP. DISPLACEMENT OF THE BLOCKS CAN BE SEEN IN THE CORNERS. LOAD
		REDUCED TO 1200 PSI.
95	00	A BULGE IN THE SPECIMEN CAN BE SEEN OVER THE UNEXPOSED FACE.
108	00	NO CHANGE.
115	00	NO CHANGE.
120	00	END OF TEST.

CROSS SECTION OF CRACK
WALL G-10

FIGURE M-3



CHAPTER N: COMPARISON OF TEST RESULTS FOR SMALL, INTERMEDIATE AND LARGE-SCALE SPECIMENS

SEC. N.1: COMPARISON OF STRENGTHS

All small-scale tests were conducted with ultimate loads applied about 10 minutes after the end of fire exposure ("hot strength tests") or more than seven days after the end of fire exposure ("residual strength tests"). The intermediate and large-scale specimens were subjected to a compressive stress of 220 psi and 110 psi respectively during fire exposure with times of failure provided in Table N-1. If failure did not occur during fire exposure, the lowest strengths were obtained between 5 to 15 minutes after the end of fire exposure as indicated by specimens G-2 and G-5. Based on the times of failure and the ultimate strength values, the small, intermediate and large-scale specimens yield very similar strength results.

SEC. N.2: COMPARISON OF BURNOUT AND EFFECTIVENESS OF PLASTER

Table N-1 provides average total depth of epoxy burnout for intermediate and large-scale specimens. For specimens without plaster such as G-2 and G-8, these results are identical to the depths of epoxy burnout obtained for small-scale specimens. Due to high moisture content and possible handling damage, most of the plaster coating on most intermediate and large-scale specimens peeled off within the first 30 minutes after initiation of the fire exposure. For small-scale specimens, the plaster did not peel off during fire exposure, but rather cracked through the base coat along the epoxy repaired crack for 3/8 in. thick plaster and formed mud type cracks in the white finish coat for 1 inch thick plaster. From the view point of actual field application, the small-scale test results are more realistic since the moisture content in the plaster of interior building walls is generally low, and considerable adhesion exists between the wall surface and the plaster.

TABLE N-1: TEST RESULTS FOR INTERMEDIATE AND LARGE-SCALE SPECIMENS

Specimen Number	Nominal Concrete Thickness (Inches)	Crack Width (Inches)	Nominal Plaster Thickness (Inches)	Time Temperature Curve	Applied Compressive Stress (psi)	Time of Failure (Minutes)	Maximum Temperature: Unexposed face (°C)	Average Depth of Spalling (Inches)	Average Depth of Epoxy Burn-out (Inches)	Time for 50% of Plaster to Peel Off (Minutes)
G-1	6	0.5	1	ASTM	220	No Failure	93	1.0	3	49.5
G-2	10	0.25	0	ASTM	220	133.25	35	1.0	2.6	----
G-3	8	0.10	3/8	SDHI	220	No Failure	17	0.5	.9	11
G-4	8	0.10	3/8	SDHI	220	No Failure	20	0.6	1.0	11
G-5	8	0.25	1	ASTM	220	136.55	25	.9	1.3	(e)
G-6	6	0.25	1	SDHI	220	No Failure	19	0	0	(e)
G-7	6	0.10	1	ASTM	220	78.7	104	1.0	2.8	51
G-8	8	0.10	0	ASTM	220	No Failure	Not Available	0.75	3.1	-----
G-9	6	(a)	(a)	ASTM	110	50	88	(c)	(c)	2
G-10	8	0.25	(b)	ASTM	110	80	61	(d)	(d)	8

(a) See page M-3 for crack widths and plaster thickness on different quadrants of specimen
(b) See page M-7 " " " " " " " " "
(c) See page M-6, Fig. M-2
(d) See page M-11, Fig. M-3
(e) Base coat not significantly damaged or cracked during 2-hour fire exposure

Section N-3: Comparison of Temperatures on Unexposed Face.

E-119 type fire exposures for walls theoretically generate thermal gradients only through the wall thickness. Hence, the temperature on the unexposed face of the walls are independent of the specimen length and width dimensions. However, the moisture content in concrete and plaster can significantly affect the temperatures within the wall and on the unexposed face. The moisture contents for the small-scale specimens were generally lower than for the intermediate and large-scale specimens (See Section A-9). Hence, the maximum temperatures on the unexposed face of the small-scale specimens were generally about 7% higher than for the intermediate and large-scale specimens given in Table N-1.

CHAPTER O: CONCLUSIONS

The following conclusions are based on test results given in previous chapters for small, intermediate, and large-scale epoxy repaired wall specimens illustrated in Fig. A-1. These conclusions are generalized, for more specific details refer to appropriate graphs and tables. Definitions for "hot" and "residual" strengths are provided in Sec. A.5.

1. Good to excellent comparison was obtained for test results of small, intermediate and large-scale specimens (See Chapter N). Therefore, the cheaper small-scale specimens described in Section A.1 can be effectively used to study the behavior and mechanical properties of epoxy repaired concrete walls subjected to fire exposure rather than the expensive full-scale specimens described in ASTM E-119 specifications.

2. The mechanical properties of all epoxy adhesives currently used for the repair of concrete structures are very similar at temperatures about 100°F above the heat distortion temperatures (110°F to 150°F). Since the thermal gradients in unplastered walls up to 10 in. thick generate temperatures above 200°F throughout most of the wall thickness, the behavior and strength properties of various epoxy adhesives in epoxy repaired concrete walls during and after fire exposure are very similar.

3. Crack width, wall thickness, type of fire exposure, type of stresses applied on epoxy repaired crack, and the presence of fire protection coatings are the primary parameters affecting the strength properties and behavior of epoxy repaired cracks in concrete walls during and after fire exposure.

4. The duration and intensity of fire exposure has great significance on the strength and behavior of epoxy repaired concrete walls both during and

after fire exposure. In this research program, the standard two-hour ASTM E-119 and the one-hour SDHI fire exposures (See Sect. A.5) were used to investigate the significance of duration and intensity. For unplastered specimens, the compressive strength properties for the SDHI fire were about two times greater than for the ASTM fire (Compare Figs. B-4a and C-4a). Similarly, the depth of epoxy burnout for unplastered specimens was about three times greater for ASTM fires in comparison to SDHI fires. Compare Figs. B-4b and C-4b .

5. For a two-hour ASTM E-119 or the one-hour SDHI fire, "hot strength" properties of epoxy repaired concrete walls from 6 in. to 10 in. thickness (except for thin epoxy injected cracks subjected to pure compressive stresses) are reduced to levels far below the original design stress levels. For example, for an 8 in. thick concrete wall with epoxy injected diagonal cracks from 0.05 in. to 0.25 in. wide and subjected to a two-hour ASTM E-119 fire, the compressive "hot strength" will vary from 200 to 600 psi.

6. The direction of the epoxy repaired crack in relation to the applied stresses has significant effect on the strength properties of epoxy repaired components during fire exposure. For thin epoxy repaired cracks subjected to normal compressive stresses, strength reduction is minimal. Epoxy repaired cracks subjected to parallel shear stresses may suffer total loss of strength depending on the thermal gradients, crack width and extent of aggregate interlock.

7. In conjunction with Conclusions 5 and 6, the loads which an epoxy repaired concrete component must transfer during a fire need to be carefully considered. For shear walls, the simultaneous occurrance of a fire and a severe earthquake or wind load is not realistic. Thus, the investigation for the strength properties and behavior of epoxy repaired concrete walls

during a fire should consider only the presence of dead loads and live loads other than the lateral wind or seismic loads.

8. Plaster coatings of about 1 in. thickness are very effective in reducing burnout of epoxy adhesive and thus greatly increasing "residual strength" in epoxy repaired cracks. However, the "hot strength" properties, such as compressive strength, are not significantly increased by plaster even up to 1 in. thickness (See Chapters G and H).

9. For epoxy repaired concrete walls, thin surface coatings such as sodium silicates or intumescent paints applied for the purpose of fire protection are either ineffective or uneconomical (See results in Chapter I).

10. Most "residual strength" properties of epoxy adhesives subjected to elevated temperatures (but not burned or pyrolyzed) are increased more than 50% (See Fig. A-3). Therefore, the unburned epoxy adhesive remaining in the crack after a fire exposure will possess higher strengths than prior to fire exposure.

11. The lowest strength properties of epoxy repaired concrete walls do not occur during fire exposure but rather five to fifteen minutes after the end of both the E-119 and SDHI fire exposures (See test results for intermediate-scale specimens in Chapter L and Table N-1). This phenomenon is due to (1) the presence of thermal gradients causing increasing temperatures at and near the unexposed face after the end of fire exposure, and (2) rapidly decreasing strengths of epoxy adhesives at temperatures above 230°F with near zero strengths at temperatures above 400°F.

12. If an epoxy repaired concrete component is exposed to fire resulting in total or partial pyrolysis or burnout of epoxy adhesive, the burnout crack or region can be effectively reinjected with epoxy adhesives or filled with epoxy grout (See Chapter J).