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SEISMIC HARDENING OF UNREINFORCED MASONRY WALLS THROUGH A SURFACE TREATMENT

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SUMMARY

SEISMIC HARDENING OF UNREINFORCED MASONRY WALLS THROUGH A SURFACE TREATMENT

The primary objective of this project was to determine the feasibility of using a coating or surface treatment to achieve seismic hardening of unreinforced masonry walls.

This was accomplished by assembling available information on methods of reinforcing existing masonry which are now in use, by reviewing available test data of unreinforced masonry, by researching available coatings, by determining anticipated required stress levels and by evaluating the results of all of these efforts toward establishing the feasibility of the idea. Since the surface bonding cement appears to have excellent possibilities, an outline for Phase II was developed.

The use of surface bonding cement to accomplish seismic hardening of existing unreinforced masonry walls is a potentially economical solution to a problem that at present only has expensive solutions.

If the use of this material tests out as anticipated, it will result in an immediately available solution for economical hardening of existing unreinforced masonry walls. This solution together with rational engineering judgment could be used to upgrade thousands of buildings in a short period of time.

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INTRODUCTION

PURPOSE

This report has been prepared to evaluate the feasibility of developing an economical and simple method of strengthening unreinforced masonry to resist seismic induced forces through the use of a coating. This study represents the first phase of a multi-phase program to develop the design criteria required of a coating or surface treatment, the capabilities of existing products and to develop a new product, if required.

GUIDELINES

The feasibility study is based on the use of existing test data, forces resulting from the assumptions in the 1976 edition of the Uniform Building Code and a comparison of the UBC requirements with the requirements of ATC-3 document, "Tentative Provisions for the Development of Seismic Design Regulations for Buildings", January 7, 1977.

METHODOLOGY

The conclusions are based on a review of the existing test data from government and industry, a series of interviews with government and industry personnel, and the application of limited engineering calculations. The conclusions represent the best professional judgment of the authors in evaluating this data in terms of their past experience in the design and rehabilition of structures to resist induced seismic forces.

SCOPE OF WORK - OBJECTIVES

The following is a description of the objectives of this Phase I study:

REINFORCING METHODS

Assemble information related to normal methods of reinforcing masonry walls. This was done through evaluation of the work of our firm and that of others.

CAPACITY OF MASONRY

Assemble information related to the capacity of unreinforced masonry through compilation of existing test data. A review of tests from the V.A. Hospital seismic projects and from Los Angeles City Schools was accomplished.

PROPERTIES OF COATINGS

Research properties and uses of available products to be applied to unreinforced masonry as surface coatings. This included the evaluation of existing test data as well as a review of available literature in the form of both technical papers and product data.

ANTICIPATED STRESS LEVELS

Determine anticipated stress levels which must be developed by masonry panels to resist seismic loads. This was done by initiating calculations for some typical buildings.

FEASIBILITY

Evaluate feasibility of proposal and establish objectives for Phase II. This involved evaluation of all of the data which was accumulated for the first four tasks.

COMMON METHODS OF REINFORCING EXISTING MASONRY

A review of the criteria which is presently used for rehabilitation of existing buildings indicates that the governing criteria of the various codes normally require that all unreinforced structural masonry be strengthened in one of two ways. Both of these methods involve the use of gunite or concrete.

RIB METHOD

Ribs or columns of concrete or gunite are incorporated into existing masonry to support vertical loads and lateral forces which are normal to the wall. Typical details of an installation of ribs without a membrane are shown in Figure 1.

In this case, the masonry is assumed to stiffen the wall for in plane shear forces, but the gunite or concrete ribs are assumed to take all of the shear.

RIB PLUS MEMBRANE METHOD

The second method of reinforcing existing masonry involves the use of the same gunite or concrete vertical ribs and an additional gunite membrane applied to the surface of the wall. Typical details of this method are shown in Figure 2.

With this method the gunite membrane is assumed to take all of the shear forces parallel to the wall, i.e., the in plane forces.

There are apparently no test results of any consequence for this type of rehabilitation of existing masonry but these two methods are basically the only ones in use. Some testing of this approach should be developed for comparison with the surface coatings method.

Extensive discussions with government engineers in California have revealed that, particularly in rehabilitation of schools, the gunite methods are basically the only ones which are acceptable in lieu of replacing the unreinforced masonry with another load carrying system. Research of available data indicates that the major percentage of seismic rehabilitation work which has been done is in California and the above methods are virtually the only ones used in lieu of demolition.

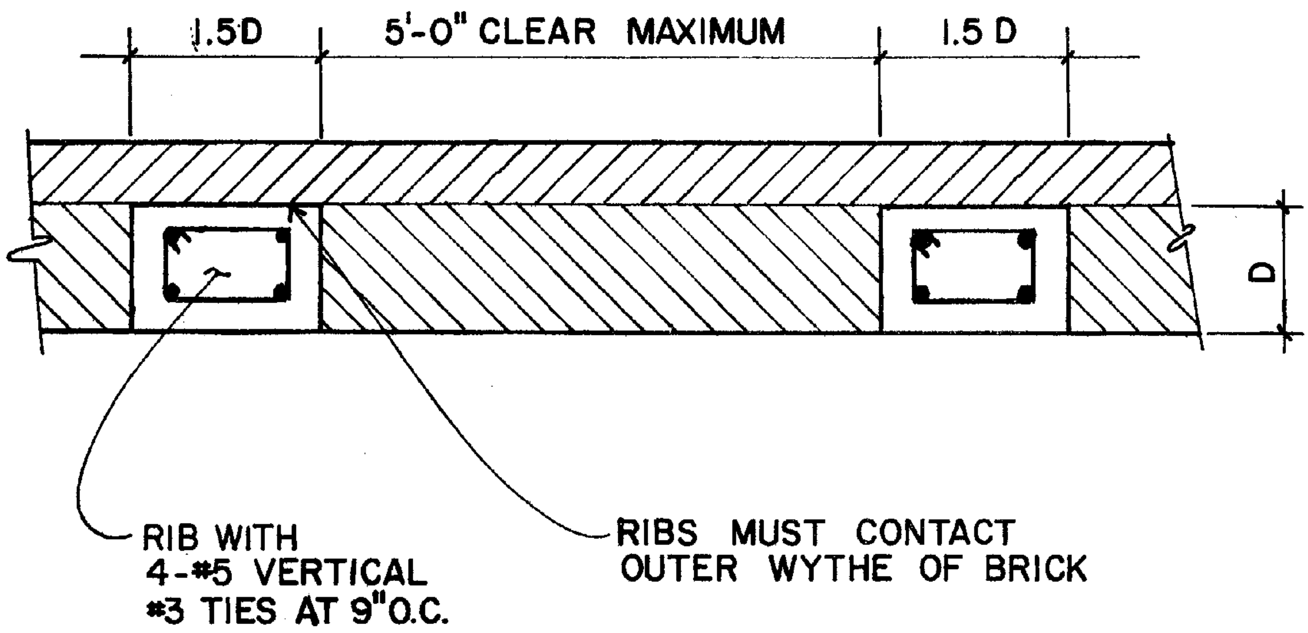


Figure 1

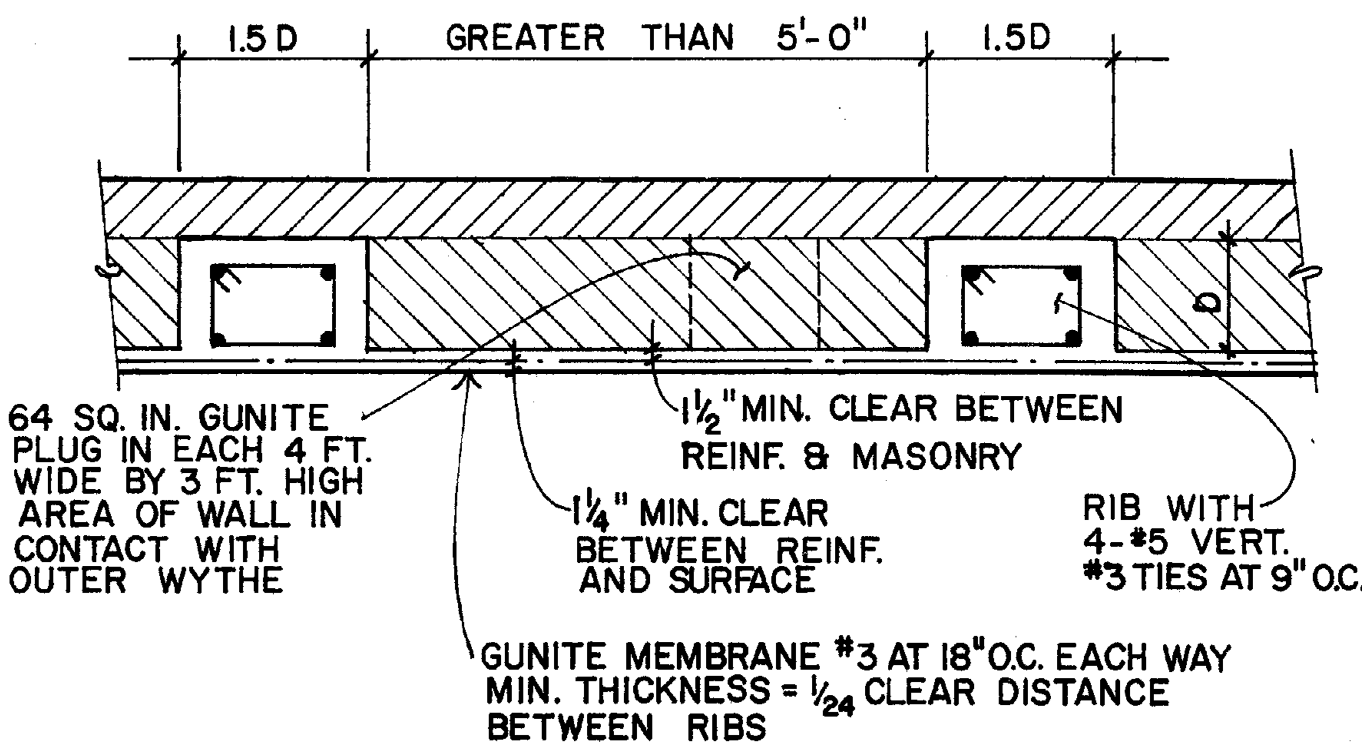


Figure 2

CAPACITY OF UNREINFORCED MASONRY IN EXISTING BUILDINGS

A review of almost 900 shear tests of unreinforced masonry from existing buildings was accomplished. These tests have been categorized by type of masonry and geographic location. The locations are shown on Figure 3 and the results are shown in Table 1.

TEST DATA REVIEW

The test data came basically from two sources. The Los Angeles City Schools provided some 473 tests of brick masonry and the Veterans Administration provided the masonry test results from their seismic rehabilitation program. The V.A. tests come from their hospitals which are located in Zone 2 or 3 as shown on the 1973 UBC map and did not have a seismic resistant design.

LOS ANGELES CITY SCHOOL MASONRY

The largest portion of the masonry which was tested came from existing brick walls. This is to be expected since the large number of tests made on samples from Los Angeles City Schools were from schools built prior to 1933. Brick masonry bearing walls were quite common during that period of time. No information is available on the exact method of testing or the number of samples that did not hold together long enough to be tested. The results of the Los Angeles tests call the shear value "Shear on Bed Joints". The assumption was made that these tests would compare with the tests from the Veterans Administration.

The balance of the brick masonry tests appear to give values which are twice those in the Western region. The tests in the West averaged 45.8 psi for a test shear value with a standard deviation of 34.8. This could yield a working or UBC code shear value of 25% of 45.8 or approximately 11 or 12 psi. Although the tests in the other areas of the country appear to be higher, such as an average of 152.4 psi in the Northeastern region, the standard deviation is 97.6. It seems reasonable that tests run on existing brick masonry from the West should be conservative for the other regions of the country.

V.A. HOSPITAL MASONRY TESTS

The Veterans Administration tests followed two approaches. The initial tests were run with approximately square samples which were removed from existing V.A. facility walls. The samples were in the range of 2' 8" to 3' 0" square. This procedure which was established for the V.A. by the National Bureau of Standards was quite costly. The per panel cost was approximately $2000. This writer participated in this type of testing procedure at two V.A. Hospitals and can verify that it was very costly as well as inconvenient since a wall was intentionally damaged and patched. Although every attempt was made to pick locations which would not cause any inconvenience to patients or staff, such was not always possible.

These problems resulted in the development of a second and much more economical procedure. This method involved the use of 6" cores cut from the existing masonry walls. The core is placed in a testing machine horizontally with the bed joint turned to an angle of 15° with the vertical. This is described in Figure 4 which also shows the method for testing square panels. The core method was compared with test results from square brick panels in a report by Testing Engineers, Inc., for the Veterans Administration entitled "Bed-Joint Shear Tests of Cylindrical Cores Compared with Diagonal Compression Tests in Brick Masonry Wallettes". This testing program was carried out using new masonry rather than masonry from existing buildings. The data indicates that the core results are very similar to the panel results. The bulk of the V.A. tests were run using the second method since the costs were only $200 per sample or 10% of the costs of the initial method.

Supplementary tests conducted by Testing Engineers, Inc., for the V.A. verify that the mortar strength is the controlling factor, or at the very least, the most important factor. For example, when the mortar strength was approximately 4000 psi, the shear test values averaged 346 psi. When the mortar strength was approximately 300 psi., the shear test values averaged 123 psi.

RESULTS

Even though the data is slight in some areas of the country and indicates a wide deviation in test results, it is possibly as good as can be obtained on existing masonry. Since the mortar or bed joint appears to be the weak plane, the workmanship of the mason and the quality of the mortar are all important and vary as people vary. The use of any coating will potentially demand a core test of the in situ masonry to verify the properties of that masonry.

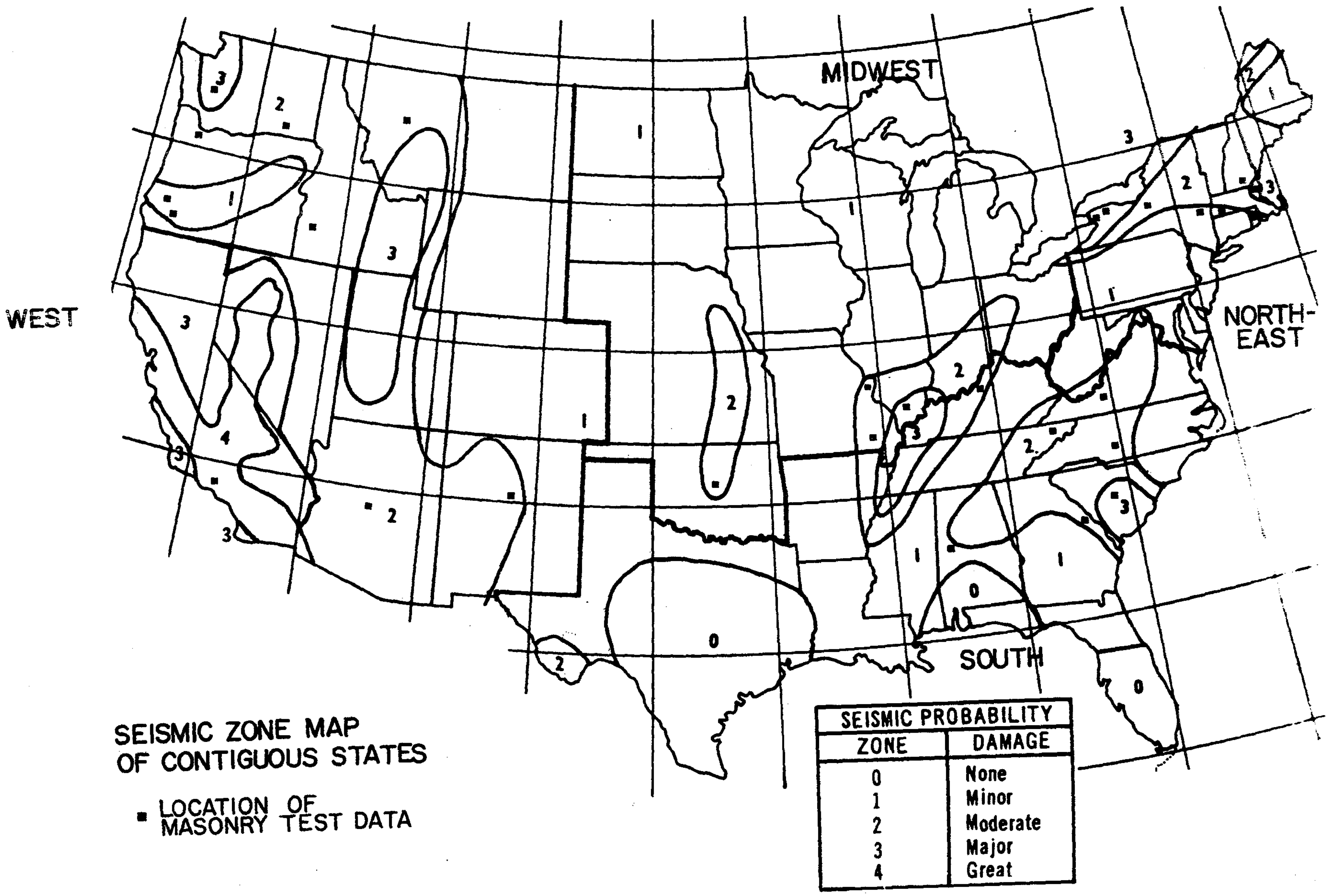
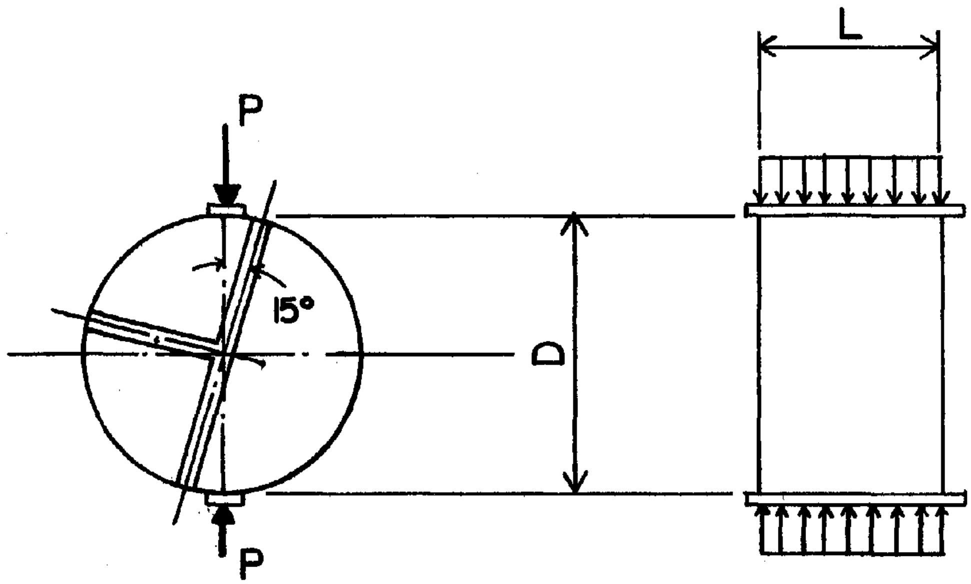

WEST
MIDWEST
NORTH-EAST
SOUTH
SEISMIC ZONE MAP OF CONTIGUOUS STATES
■ LOCATION OF MASONRY TEST DATA
SEISMIC PROBABILITY
ZONE DAMAGE
0 None
1 Minor
2 Moderate
3 Major
4 Great

Figure 3

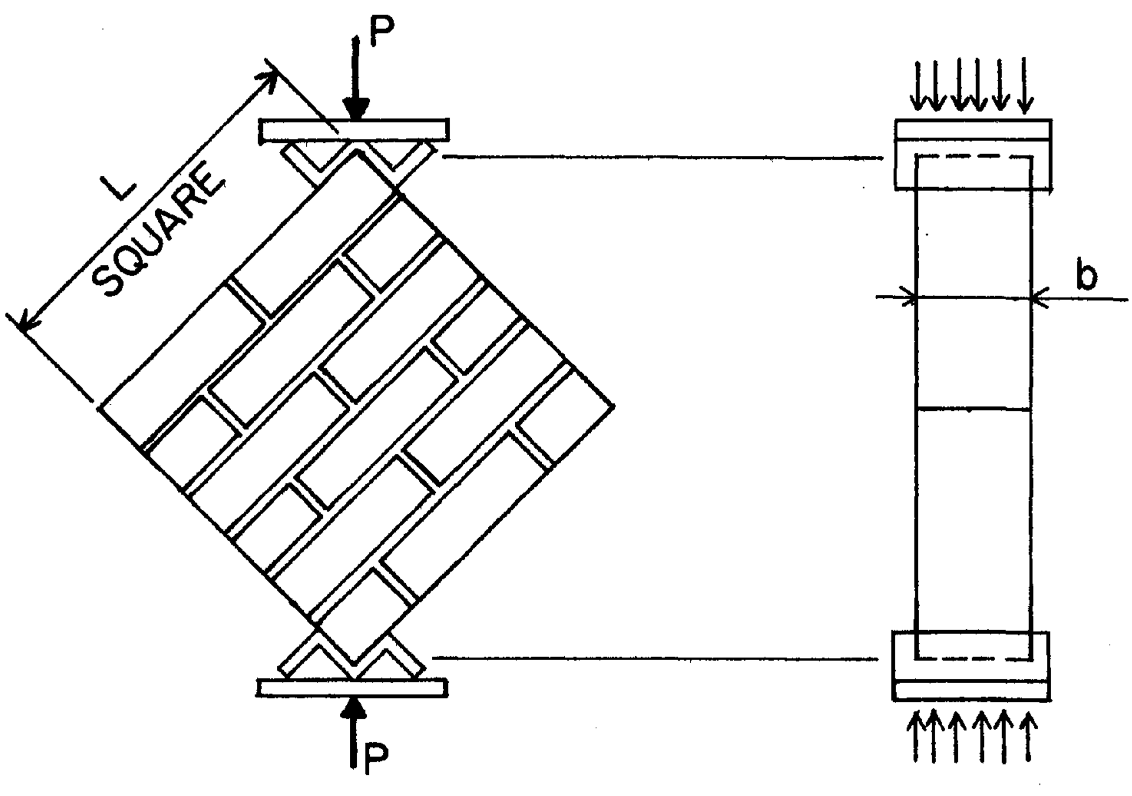
TABLE 1

AVERAGE MASONRY TEST VALUES -- SHEAR

		BRICK	CLAY TILE	CONCRETE BLOCK	BRICK & BLOCK	BRICK & BLOCK
NORTH EAST	NO. OF TESTS AVERAGE (PSI) DEVIATION C.O.V.	85 152.4 97.6 64%	66 86.6 51.2 59%	47 74.4 50.9 68%	10 127.8 64.8 50%	Insuffi-cient Data
MIDDLE WEST	NO. OF TESTS AVERAGE (PSI) DEVIATION C.O.V.	39 218.4 97.8 45%	4 62.6 40.9 65%	NO DATA	5 92.9 25.4 27%	NO DATA
SOUTH	NO. OF TESTS AVERAGE (PSI) DEVIATION C.O.V.	55 107.3 85.4 80%	21 112.7 105.1 93%	17 87.0 58.5 67%	9 101.0 35.0 35%	7 62.7 28.1 45%
WEST	NO. OF TESTS AVERAGE (PSI) DEVIATION C.O.V.	507 45.8 34.8 78%	9 45.0 15.1 34%	Insuffi-cient Data	NO DATA	5 61.3 29.6 48%
NATIONAL	NO. OF TESTS AVERAGE (PSI) DEVIATION C.O.V.	686 73.8 76.1 103%	100 87.4 65.9 75%	64 77.8 52.8 68%	24 110.5 49.1 44%	12 62.1 27.4 44%



BED-JOINT SHEAR TEST



DIAGONAL COMPRESSION TEST

Figure 4

AVAILABLE COATINGS FOR MASONRY

PLASTER

Coating of unreinforced masonry for seismic hardening was first considered in the 1950's by the Los Angeles City Board of Education through the use of reinforced plaster. The process is described by Edwin H. Stahl in a paper entitled "Surface Application of Masonry Reinforcement". This involved the use of reinforced cement plaster. For forces parallel to the wall, the shear was assumed to be totally carried by the reinforced plaster with no credit given for the masonry. Apparently this scheme was never used on a total building project. Although it was reported to be less expensive than the conventional gunite and ribs approach, it was still very costly.

SURFACE BONDING CEMENT

One coating product which is available on the market today has a generic name of surface bonding cement or surface bonding mortar. This product was developed in the 1960's by the Research Section of the U.S. Department of Agriculture for use in the construction of concrete masonry walls without mortar.

Three prominent manufacturers of surface bonding cements were contacted and all supplied significant quantities of test data and other detailed information. All of the testing of this product has been on concrete masonry with no bed joints and either with or without grout and reinforcing in the cores. Wall panels of 8" concrete masonry units laid dry have been tested in racking shear and give test values of 30 to 50 psi based on the gross area. The tests were conducted using the procedures in ASTM E72. The surface bonding cement also contributes to a significant improvement in the flexural capabilities of the masonry.

The surface bonding cements are basically Portland cement mortar with glass fibers added. The material may be applied either by hand trowel or by spraying to a thickness of approximately 1/8 inch.

The basic allowable design stresses as they would apply to dry laid concrete masonry and working loads are as follows:

SHEAR:	10 psi based on gross area
FLEXURAL:	HORIZONTAL SPAN:
	30 psi based on gross area for running bond
	18 psi based on gross area for stacked bond
	VERTICAL SPAN:
	18 psi based on gross area

Surface bonding cements have been tested on 8" concrete masonry walls to a satisfactory two-hour fire test.

Although other coating materials for masonry are available such as epoxy and plaster, the surface bonding cements appear to yield the most promise.

ANTICIPATED STRESS LEVELS REQUIRED OF NORMAL MASONRY

This study assumes that the basic building which needs to be rehabilitated is the small unreinforced 1, 2 or 3 story masonry bearing wall building. This is the type that exists by the thousands throughout California and other areas of the United States where there is a high seismic risk.

TYPICAL MASONRY STRESSES

A typical small building that is 50' x 100' in plan was selected for study as shown on the sample problem. Stresses were calculated for 1, 2 and 3 story buildings for the 1976 Uniform Building Code, including all four zones. The anticipated shear stresses are all below 20 psi.

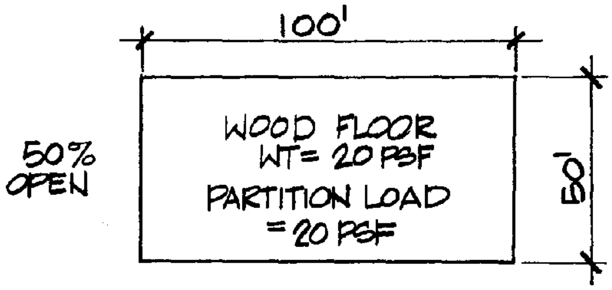
Stresses were also determined using the criteria in ATC-3. The masonry was assumed to act as shear walls rather than as unreinforced masonry and masonry stresses were calculated for a maximum velocity of 0.4g and of 0.05g. The reinforced masonry shear wall assumption was used to get a rational value for a rehabilitated building. The anticipated shear stresses for unreinforced masonry by ATC-3 range as high as 65 psi for 0.4g. The maximum 1976 UBC value and the ATC-3 value indicate that they are comparable.

Out of plane forces or forces normal to the plane of the walls have been evaluated for 12" brick walls with 8', 10' and 12' story heights. Those flexural stresses range from 18 psi to 2 psi including the effects of all four 1976 UBC Zones. The tests on dry laid masonry have already indicated that a surface bonding cement with no help from the mortar can exceed these flexural stresses. The ATC-3 requirements appear to require a greater stress which will require flexural testing of mortared masonry with surface bonding cement.

Overturning problems in masonry bearing wall buildings are apparently severe in some cases but may in fact be minimized by the dead weight of the masonry and the assumption of a triangular stress distribution across the wall. Studies of this are being conducted by others. The resultant chord forces will have to be resolved but are not a part of this study. The solutions can be simple exterior application of steel angles or similar tension-capable materials.

With the addition of a coating, existing masonry will have some ductility and will also achieve a shear capacity derived from the mortar strength and the coating strength. Assuming that the coating will also have a confining effect, it should be reasonable to base the design allowables for 1976 UBC stresses and ATC-3 stresses at 25% to 30% of test values.

TYPICAL EXAMPLE 1 :



1976 UNIFORM BUILDING CODE
STORY HEIGHT= 10'-0"
1'-0" THICK SOLID BRICK WALLS
DIAPHRAGM IS ASSUMED TO BE FLEXIBLE.
FORCES DIVIDE EQUALLY TO EXTERIOR WALLS.

	W	T LONG SIDE	T SHORT SIDE	BASE SHEAR
1 STORY	400^k	0.05	0.07	74.5^k
2 STORY	900^k	0.10	0.14	167.6^k
3 STORY	1400^k	0.15	0.21	260.7^k

$$V = ZKCSIW = (1.0)(1.33)(0.14)(1.0)W = 0.19W$$
$(CS = 0.14)$

BASE SHEAR

	W	ZONE 4 $V=0.19W$	ZONE 3 $V=0.14W$	ZONE 2 $V=0.07W$	ZONE 1 $V=0.04W$
1 STORY	400^k	74.5^k	56.0^k	28.0^k	16.0^k
2 STORY	900^k	167.6^k	126.0^k	63.0^k	36.0^k
3 STORY	1400^k	260.7^k	196.0^k	98.0^k	56.0^k

MASONRY SHEAR STRESSES AT BASE (PSI)

		ZONE 4	ZONE 3	ZONE 2	ZONE 1
1 STORY	SHORT DIRECTION*	5	4	2	1
	LONG DIRECTION	3	2	1	1
2 STORY	SHORT DIRECTION*	12	9	4	3
	LONG DIRECTION	6	4	2	1
3 STORY	SHORT DIRECTION*	18	14	7	4
	LONG DIRECTION	9	7	3	2

* STRESSES IN WALL WITH 50 % OPENINGS MAY REQUIRE OTHER REINFORCING.

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TYPICAL EXAMPLE 2a: SAME BUILDING AS IN EXAMPLE 1

ATC-3 $V = C_S W_D$ + $C_S = 1.2 A_2 S / R T_R^{2/3}$

$R = 1.2$ UNREINFORED MASONRY — TABLE 2-A, p. I-10

$S = 1.5$ — TABLE 2-C, p. I-13, TYPE C SOIL

$0.05 < A_2 < 0.40$ — TABLE RA-1, p. RA-1

$T_R = 0.05 h_n / \sqrt{D}$

FOR 3 STORY, 50'x100' BUILDING		2 STORY	1 STORY
$T_{R\,SHORT} = 0.05(30)/\sqrt{50}$	= 0.21	0.14	0.07
$T_{R\,LONG} = 0.05(30)/\sqrt{100}$	= 0.15	0.10	0.05

C_S NEED NOT EXCEED $2.0 A_1 / R = 2.0(0.4)/1.2 = 0.67$

$2.0(0.05)/1.2 = 0.08$

C_S:

($@ A_2 = 0.40$)	3 STORY	2 STORY	1 STORY
SHORT DIRECTION	1.70	2.24	3.56
LONG DIRECTION	2.14	2.81	4.47

USE $0.67 = C_{S\,MAX}$

($@ A_2 = 0.05$)	3 STORY	2 STORY	1 STORY
SHORT DIRECTION	0.23	0.30	0.48
LONG DIRECTION	0.29	0.37	0.60

USE $0.08 = C_{S\,MAX}$

			$@ A_2 = 0.40$		$@ A_2 = 0.05$	
		W	FORCE	STRESS	FORCE	STRESS
1 STORY	SHORT DIRECTION*	400^k	268^k	19 psi	32^k	2 psi
	LONG DIRECTION			9 psi		1 psi
2 STORY	SHORT DIRECTION*	900^k	600^k	42 psi	48^k	3 psi
	LONG DIRECTION			21 psi		2 psi
3 STORY	SHORT DIRECTION*	1400^k	938^k	65 psi	112^k	8 psi
	LONG DIRECTION			33 psi		4 psi

*STRESSES IN WALL WITH 50% OPENINGS MAY REQUIRE OTHER REINFORCING.

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TYPICAL EXAMPLE 2b: SAME BUILDING AS IN EXAMPLE 1

ATC-3 $V = C_S W_D$ & $C_S = 1.2 A_2 S / R T_R^{2/3}$

R = 4 REINFORCED MASONRY SHEAR WALLS — TABLE 2-A, p. I-10
S = 1.5 — TABLE 2-C, p. I-13, TYPE C SOIL
$0.05 < A_2 < 0.40$ — TABLE RA-1, p. RA-1

$T_R = 0.05 h_n / \sqrt{D}$

FOR 3 STORY, 50'x100' BUILDING		2 STORY	1 STORY
T_R SHORT $= 0.05(30)/\sqrt{50} = 0.21$		0.14	0.17
T_R LONG $= 0.05(30)/\sqrt{100} = 0.15$		0.10	0.05

C_S NEED NOT EXCEED $2.0A_1/R = 2.0(0.4)/4 = 0.20$
$2.0(0.05)/4 = 0.025$

C_S: (@ $A_2 = 0.40$)	3 STORY	2 STORY	1 STORY
SHORT DIRECTION	0.51	0.67	1.07
LONG DIRECTION	0.64	0.84	1.34

USE 0.20 = C_S MAX

(@ $A_2 = 0.05$)	3 STORY	2 STORY	1 STORY
SHORT DIRECTION	0.07	0.09	0.14
LONG DIRECTION	0.09	0.11	0.18

USE 0.025 = C_S MAX

		W	@ $A_2 = 0.40$ FORCE	@ $A_2 = 0.40$ STRESS	@ $A_2 = 0.05$ FORCE	@ $A_2 = 0.05$ STRESS
1 STORY	SHORT DIRECTION*	400k	80k	6 psi	10k	1 psi
	LONG DIRECTION			3 psi		1 psi
2 STORY	SHORT DIRECTION*	900k	180k	13 psi	23k	2 psi
	LONG DIRECTION			6 psi		1 psi
3 STORY	SHORT DIRECTION*	1400k	280k	20 psi	35k	3 psi
	LONG DIRECTION			10 psi		1 psi

*STRESSES IN WALLS WITH 50% OPENINGS MAY REQUIRE OTHER REINFORCING.

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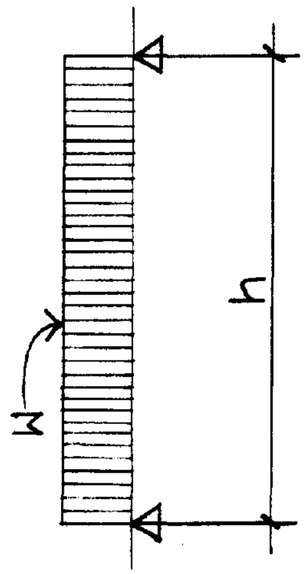
SEISMIC INDUCED BENDING PERPENDICULAR TO PLANE OF WALL



WALL THICKNESS 12"
WALL WEIGHT 120#/SF OF WALL

$f = M/S$
$M = wh^2/8$
$S = bd^2/6 = 288 \text{ IN}^3$

$w = ZIC_pSW_p$
$= Z(1.0)(0.20)(1.0)W_p$ UBC EQ 12-8

OR

$w = C_pPW_pA_2$
$= 0.9(1.0)W_pA_2$ ATC-3 EQ 7-1

MASONRY STRESSES (PSI)

	UBC				ATC-3	
ZONE	4	3	2	1	$A_2=0.40$	$A_2=0.05$
w	$0.20W_p$	$0.15W_p$	$0.08W_p$	$0.04W_p$	$0.36W_p$	$0.045W_p$
h=8'	8	6	3	2	14	2
h=10'	13	9	5	3	23	3
h=12'	18	14	7	4	32	4

CATEGORY A CONSTRUCTION

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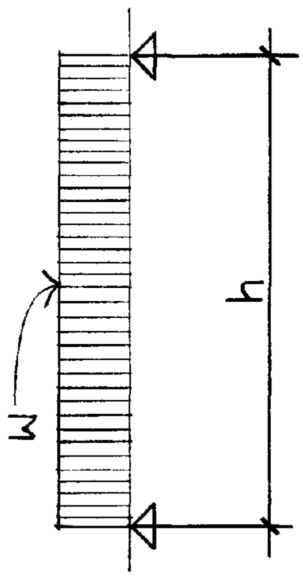
SEISMIC INDUCED BENDING
PERPENDICULAR TO PLANE OF WALL



WALL THICKNESS 8"
WALL WEIGHT 80 #/SF OF WALL

$f = M/S$
$M = wh^2/8$
$S = bd^2/6 = 128 \text{ IN}^3$

$w = ZIC_pSW_p$
$= Z(1.0)(0.20)(1.0)W_p$ UBC EQ 12-8

OR

$w = C_pPW_pA_2$
$= 0.9(1.0)W_pA_2$ ATC-3 EQ 7-1

MASONRY STRESSES (PSI)

	UBC				ATC-3	
ZONE	4	3	2	1	$A_2 = 0.40$	$A_2 = 0.05$
w	$0.20W_p$	$0.15W_p$	$0.08W_p$	$0.04W_p$	$0.36W_p$	$0.045W_p$
h=8'	12	9	5	2	22	3
h=10'	19	14	8	4	34	4
h=12'	27	20	11	5	49	6

CATEGORY A CONSTRUCTION

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FEASIBILITY OF PROPOSAL AND OBJECTIVES FOR PHASE II

FEASIBILITY

The proposal to develop an economical and simple method of reinforcing masonry to resist seismic forces through the use of a coating is definitely feasible. The gunite methods of reinforcing masonry are apparently effective but very expensive. Experience shows that this type of solution could easily cost $10 to $12 per square foot of existing building. Depending on the wall to floor area ratio, a solution using a surface bonding cement could be 25% or less of the cost of the gunite method.

There are apparently ample tests on mortared masonry from existing buildings available and also many tests of dry laid masonry with a surface bonding cement. There are no tests available with surface bonding cements used on mortared masonry. This is where the objectives of Phase II begin.

OBJECTIVES

The objectives of Phase II are as follows:

1. Build and test sample panels of mortared brick masonry and surface bonding cement in racking shear and flexure.

2. Test 6" cores to corroborate the core test and wall panel test values for a mortared brick masonry with surface bonding cement. This program would be similar to that done for the V.A. by Testing Engineers, Inc.

3. Evaluate the test results of this first series of tests against the anticipated required stress levels.

4. If core relationship can be corroborated, prepare cores from surface bonding cement coated existing masonry taken from California brick masonry buildings. This relates to the Los Angeles City School tests which were significantly lower than those from other parts of the country.

If results of objective 2. are not conclusive, then it will be necessary to test panels from existing California buildings.

5. Evaluate the test results of this second series of tests against the anticipated required stress levels.

6. Check test results with samples from the Northwest, Northeast and Southeast.

7. Run tests on California masonry using the gunite method of rehabilitation. This will give a basis for comparing the surface bonding cement solution with the presently accepted method.

8. Test samples with California masonry and surface bonding cement using cyclic or dynamic procedures for loading.

9. Prepare design criteria for the use of surface bonding cements for seismic hardening of unreinforced masonry.

CONCLUSIONS

The use of surface bonding cement to accomplish seismic hardening of unreinforced masonry walls is a potentially economic solution to a problem that at present only has expensive solutions.

This solution does not address all of the problems inherent in hardening of existing building such as anchoring of diaphragms or lack of chord elements but it does offer substantial additional safety for the buildings' inhabitants and those people outside the building who might get hit by falling masonry. The confining effect of the coating and the ductility it furnishes are equally as important as the added shear capacity.

If the use of this material tests out as anticipated, it will result in an immediately available solution for economical hardening of existing unreinforced masonry walls. This solution together with rational engineering judgment could be used to upgrade thousands of buildings in a short period of time.

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