A CASE HISTORY - RETROFIT SEISMIC STRENGTHENING OF JOHN MARSHALL HIGH SCHOOL WITH HISTORIC RESTORATION OBJECTIVES

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SUMMARY

This paper presents a discussion of the practical engineering and construction aspects of the seismic strengthening and faithful restoration of a major school building of historic significance located in Los Angeles, Calif. The building was built prior to the California Field Act of 1933 and did not posess the design and construction attributes to enable it to resist seismic forces consistent with present day technology. Selections of materials and construction methods appropriate to the type of construction were of importance in the design and execution of the work and will be discussed herein.

INTRODUCTION

The Administration and East Classroom Buildings of John Marshall High School in Los Angeles, the best remaining example of collegiate gothic style of school architecture in Southern California, built during the the years of 1929 and 1931, became one of the last pre-1933 masonry buildings in the Los Angeles Unified School District to be strengthened to meet modern earthquake code requirements. Because of the historic significance of these buildings and their architectural quality, faithful restoration of the archtectural features and modernization of plan and functional elements were included in the requirements of the project. Design was commenced in early 1975, construction was commenced in 1977, and completed in fall, 1980.

Cost of rehabilitation, restoration and modernization of these buildings was approximately 5.2 million dollars, an average of about $47.75 per square foot. The District had originally contemplated demolition of the buildings and their replacement with new construction. Determined action by alumni, students, teachers and residents of the area resulted in reconsideration of the original decision. A feasibility study suggested that the buildings met the criteria for rehabilitation and the decision was made to proceed with the project on that basis.

DESCRIPTION OF THE BUILDINGS

Buildings are 3 stories high with a central tower 95 feet (29 M) high at the entrance of the administration building. Buildings are supported by a foundation system of concrete spread footings. Structure is a reinforced concrete frame with ribbed concrete floor and roof construction. Walls are of unreinforced brick, some being bearing walls, the remainder being infill. Interior partitions were unreinforced hollow clay tile. Exterior surfaces are heavily ornamented with cast stone, and penetrated by many windows.

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The area of the Administration (Main) Building consisting of 3 floors and the tower is 56,220 sq. ft. (5223 M^2); the area of the East Classroom consisting of 3 floors is 35,844 sq. ft. (3330 M^2), for a total area of 92,064 sq. ft. (8553 M^2).

ANALYSIS AND DESIGN CONSIDERATIONS

Analysis of the existing structure, based on the original drawings revealed that the building was deficient in foundation capacity, and in wall areas available for development of shear resistance due to the large areas of wall lost to openings such as windows and doors. The building, with its predominantly 17-inch (432 mm) thick brick walls and heavy cast stone ornament constituted considerable weight to be dealt with in the seismic design. Additionally, there was a lack of adequate continuity elements for distribution of forces, both horizontally and vertically. The reinforced concrete frame and ribbed concrete floors and roofs were found to be adequate for gravity loads. This information was obtained by a structural design check.

As a result of analysis, principal lines of seismic resistance in the longitudinal direction were transferred to the interior corridor wall lines where massive 17-inch (432 mm) thick reinforced shotcrete walls extending to the footings could be provided. The shear walls were placed at appropriate locations in column bays, reinforced to include the existing columns and girders in their mass. Transverse shear wall capacity was provided by removal of one or more interior wythes of brick and replacing that thickness with bonded, reinforced gunite ribbed membrane overlays to the original wall lines.

To provide continuity in the horizontal direction and to tie elements together, reinforced shotcrete or concrete drag struts of required capacity were provided. Longitudinally, they were placed as shotcrete, bonded to the sides of the existing corridor girders. Transversely, they were placed as cast-in-place concrete through slots cut in the floor slabs between two ribs laterally restrained with bolts and washers through the ribs. These ties also served as supports for the reinforcing steel.

Vertical continuity and resistance of shear panels to overturning required substantial vertical tensile reinforcement placed at the edges of the shear panels. This required that they pass through the existing concrete girders at the corridor lines. Vertical holes were drilled in the girders to enable the reinforcing bars to pass continuously from one story to the next. The lengths of tensile bar splices for the larger bars in some cases exceeded the available story heights. Accordingly, most of the splices were made with full-penetration butt welds just above each floor level.

Exterior longitudinal walls were not used as shear elements. They were reinforced for out-of-plane bending with reinforced ribs of shotcrete placed in chases in the walls cut to remove all brick except the exterior wythe. Similar ribs were placed at the perimeters of all of the windows. This network of ribs also serves to reduce the sizes of unreinforced brick infills, stabilize the walls and provide a medium for anchorage of the exterior cast stones. The ribs were anchored to the existing reinforced concrete framing with dowels bonded into the concrete with epoxy resins as described below.

PRELIMINARY SURVEY AND EXAMINATION

An essential part of the development of this type of project requires a thorough survey and investigation of the existing structures to determine to the greatest practical extent, the following types of information:

- The layout and dimensional characteristics of the building.
- Identification of structural elements, their sizes, reinforcing, connections and locations in the structure.
- The spatial relationships of all of the materials to be considered.
- Composition, strengths and quality of the materials in the building.
- Verification of the presence or absence of accessories such as veneer ties, anchorages, stiffeners and similar items.
- Existing conditions, including those in concealed spaces, if possible.

A primary resource is a complete set of record (as-built) drawings and specifications, which may reveal much but not all the information required. The remaining information must be gained by on-site survey work, taking and testing samples from the building, and some minor destructive work to obtain access for visual examination or testing of concealed elements to determine their usefulness.

For this project, a complete set of original Contract Drawings was made available. The original design provided for terra cotta exterior ornament and veneers, but a revision was made before construction changing the terra cotta ornament and veneer to cast stone, and a record set of drawings was not available delineating these details, nor were shop drawings for the cast stone available. This necessitated more extensive on-site investigation and discovery work to determine the sizes and layout of the stones, the details of anchorage, and the details of joinery. Removals of wall materials from the interior were done to obtain necessary facts. Core specimens from brick and concrete were extracted and tested. The buildings were in service while this work was done which limited the amount of destructive work was done and some information could not be obtained. Assumptions based on our experience with similar types of construction were made to cover the unknown conditions, and these were verified during construction. Adjustments were made during construction for each condition varying from the assumptions made or information obtained from the drawings.

From the preliminary investigation, it was found that:

- Concrete was of good quality and adequate strength, reinforced essentially as shown on the Contract Drawings.
- Brick were sound, of good quality, and workmanship was good. Exterior face brick were pointed with portland cement mortar, but the balance of the brick were laid in lime mortar.
- Cast stone was set in portland cement mortar.
- Cast stone ornament and veneers were anchored to the brick backup walls either insufficiently or not at all.
- Cast stone window mullions, built on structural steel backing members were insufficiently anchord and grouted, and the backing members were not laterally supported at their ends.

MATERIALS AND METHODS OF CONSTRUCTION

Every project of this type involving extensive removals of materials, retrofit installation of new additional materials or replacement of existing materials, and working to preservation objectives where existing materials must remain and be affected to the minimum extent requires thoughtful and innovative planning, design and detailing. The planning must consider not only the selection of appropriate materials and the details related to their use, but must anticipate the methods and sequences of the work of execution, and provide necessary safeguards and complete instruction for workmen who may never have had experience with the nature of the work they are called upon to perform.

Complete and lucid delineation of the required work in details on the drawings, and complete specifications, explanatory in detail are required to communicate the work of the design professionals. Every minor detail is important. New materials and procedures or techniques which may not be well known should be qualified by samples and qualification tested where appropriate. Experience of the design, materials and methods engineering, specification personnel in the design team is of paramount importance. Specialists and knowledgeable materials manufacturers should be consulted, and available technical documents and technical standards should be researched. To wait until the project is under construction to attempt to solve some of the technical problems of the project is destructive to the quality, cost and progress of the project.

Where restoration objectives are a part of the project requirement, it is our practice to anticipate performing the strengthening work from the interior of the structure or on the backs of the elements which have architectural qualities to be preserved, to the maximum extent possible. Where work must be performed on preserved surfaces and elements, they should be modified or penetrated to the minimum extent possible, and then only with compatible, matching materials and details thoughtfully worked out and done with best workmanship and care.

Such was the case at John Marshall High School. Since the building interior was to be modernized to provide a modern, efficient school plant, most of the interior was to be removed so that most of the strengthening work was done from the interior. The only exceptions were the anchorage of brick and stone veneer areas that could not be approached from the interior, a portion of the building that was modified to provide for access to all areas by the physically handicapped, and the development of a new entrance to the rear of the building from a new courtyard within the campus. All other exterior aspects of the buildings appear at completion exactly as they originally were built, as is the main entrance lobby.

We now come to the bolts and nuts part of this discussion - namely, the materials and methods as designed and used to perform the work, and particularly, those which are considered unique or special in obtaining the result that was achieved in the execution of this project. They are presented both as materials or methods in their nature and application, or as elements in the building and the manner in which they were treated.

1. Concrete: As used here, concrete is considered to be either cast-in-place ready-mix concrete or air-placed concrete, which will be referred to by its more familiar name, "shotcrete". A majority of the work was done using shotcrete, both wet-mix and dry-mix, due to its ability to be placed in locations and conditions not readily accessible for formwork or placing concrete by conventional means. Additionally, retrofit work requires concrete to be placed between existing elements where an intimate interface is required, for which shotcrete is indicated.

Shotcrete is ideally suitable for such conditions. Wet-mix shotcrete is pre-mixed concrete, pumped to placement location by a high-capacity pump and propelled onto the receiving surface by compressed air at the nozzle. Dry-mix shotcrete, also called "gunite" is batched and mixed dry to proper proportions in a portable machine called a cement gun, transported in a flexible hose by compressed air to placement location where it is hydrated by a water ring at the nozzle and propelled onto the receiving surface by compressed air. Each has its own characteristics and benefits. Wet-mix shotcrete has a higher production rate and is ideal for placing large volumes and massive sections. However the material flow is not easily modulated and cannot be throttled down for small elements and thin sections where more control is essential. Dry-mix shotcrete places less volume, but the material flow can be reduced readily to provide good control for placing of small elements, thin sections and in confined spaces. Both methods were used in this project.

Project specifications provided that where any type or method of placement could be used, the selection was at the option of the Contractor. Where a specific type of concrete or method of placement was desired or required that type or method was designated on the drawings. In general the following schedule illustrates the principal uses of each on the Project.

a. Cast-in-place Concrete: Accessible footings, footing walls, slabs, walls, columns, beams, girders, stairs, filling of large voids.

b. Wet-mix Shotcrete: Footings, foundation walls, footing additions, mostly underfloor not accessible to conventional placing or construction of formwork; massive shearwall elements except the closures at the tops under corridor beams; membrane overlays over 6 inches (152 mm) in thickness.

c. Dry-mix Shotcrete: Ribs in brick walls; edges of openings; membrane overlays on brick walls 6 inches (152 mm) in thickness; closures at tops of massive shearwalls (the wet mix placement was tapered at a 45 degree angle at the top just clear of existing concrete soffits above and the intervening space was finished with dry-mix); anchor plugs for cast stone anchorage in brick walls; cast stone mullion backup cover or wind posts, and similar conditions.

Concrete strength for this project was selected as 3000 psi (20684 Pa), which was adequate and compatible with strengths of existing concrete.

2. Epoxy Resins: The availability of structural grades of epoxy resins to engineering and construction practice has proven of significant help in the work of strengthening and restoring buildings. Its primary uses are as structural adhesives; as injection bonding compounds to restore cracked concrete; as bonded overlays or patching mortars; as light, cohesive fills (foams); and as dowel grouting compounds. Although the author has had opportunity to utilize these useful compounds in all of the above applications, the condition and requirements of the subject project required their use only as dowel grouting compounds. More than 16,000 reinforcing steel dowels ranging in size from #4 to #11 and more than 40,000 small diameter stone anchor rods were installed using epoxy dowel grouting compounds.

   Use of epoxy resins for dowel or threaded anchor rod grouting should be carefully considered and researched, and they should be specified in terms of the properties required. Strength, viscosity, pot life, gel times and hardness or flexibility factors should be specified. Their ability to set and cure in the presence of moisture also is usually a requirement for this type of work. Only those compounds with which the materials engineer has had successful experience should be specified. Otherwise, specifications should require prior qualification testing under conditions representative of actual use at the Project. In the case of this Project, compounds from 4 manufacturers were trial tested. Two failed and were rejected, and two passed the qualification test and were used. The testing will be discussed further under the heading "Quality Assurance", below. Details of installation of anchors in epoxy resins are discussed under the heading "Dowels and Anchors", below.

3. Dowels and Anchors: Dowels of reinforcing steel were required for anchoring of all new concrete and shotcrete panels, ribs, columns, drag struts, shear wall elements and overturning tension ties. Anchors of threaded rods were used for special anchors for hardware, and anchorage of cast stone ornament and veneers. Such anchors may be set in cementitious grouts, non-shrink metallic grouts or by connection to plates or hardware when opposing connection ends are available or accessible. Additionally, mechanical expansion anchors were used where their use was indicated and their lower values suitable.

   Reinforcing steel dowels were specified to be set by use of epoxy resin or by cementitious or metallic grouts. Epoxy resins were preferred due to their requirement for a much smaller hole - important in existing work where there is frequently congestion of reinforcing steel. The dowels, as set were required to withstand withdrawal forces of 125 percent of yield strength of the bar to prequalify the grouting material and the method of installing the dowel, without any movement of the dowel from the hole. After qualification, one of every three dowels placed in the work was proof tested to a level of 80 percent of yield. After the prequalification tests were completed for all sizes of bars, more than 5000 withdrawal tests were made without a single failure.

   Threaded anchor rods were also set using epoxy resins. They were subto the same qualification and proof testing with similar results.

Mechanical expansion anchors were also used for anchorage of cast stone veneer, installed through the wall to anchor into the stone. Threaded rods were run into the anchors and hooked at their free ends to be encased in gunite ribs, membranes or anchor plugs. Criteria for anchorage of the stone provided that an anchor was to be provided for every 50 pounds (227 kg) of every stone. They were also qualification and proof tested. An occasional defective anchor was found, usually due to workmanship. For these, one additional test was performed for every unit that failed, and if a 10 percent frequency occurred, all anchors in that group were tested.

In some instances, access for installation for anchor rods for cast stone was not available, and those anchors were set from the exterior using a stepped hole. First a 3/4-inch (19 mm) hole was drilled 2 in. (51 mm) into the stone. Then a 3/8-inch (10 mm) hole was advanced into the concrete or shotcrete element on the opposite side of the wall, the hole was cleaned, epoxy resin injected and a threaded rod embedded full depth into the hole with a nut and washer bearing on the shoulder at the bottom of the first hole. Then a designed matching patching mortar was placed to patch the hole, and was textured to match the finish.

Brick veneer spandrels occurring over perimeter floor beam framing was anchored by routing out the mortar in horizontal joints in the brick, to half the brick depth, setting threaded rods as described above. The threaded rods were 3/8 in. (10 mm) diameter. The ends were hooked and engaged a #9 gage continuous horizontal wire laid in the bottom of the routed joint. Following this, the joint was repointed with mortar to match the existing masonry.

Technique for installing dowels and anchors was specified with emphasis given to avoidance of conditions for failure, and with a schedule of hole sizes on the drawings. Frequent causes of failure have been found in the experience of the writer to be:

° Improper or insufficient mixing of epoxy compound.
° Holes drilled with rotary drills with drilling dust embedded in the smooth hole sides.
° Insufficient coating of epoxy resin on bar (when thixotropic resins are used).

Specifications should include: Bars should be clean and free from oil; holes should be drilled with percussion equipment, hollow rock bits to produce coarse cuttings and compressed air to blow the cuttings out of the hole during drilling; if rotary or rotary impact drills are used fine drilling dust is produced, wash out holes with a non-oily solvent such as toluene and a bottle brush; use a thixotropic epoxy compound for horizontal and overhead holes and coat the rod with epoxy prior to insertion into the hole (medium viscosity epoxy compounds may be used for downhand holes); use duct tape with a small slit cut for the rod to seal holes and prevent epoxy material from running out of overhead or horizontal holes; use a caulking gun or for large jobs, a pressure gun with a long tip to place epoxy resin into holes, and holes should be filled approximately 2/3 full; insert rod slowly.

Schedule of hole sizes: This schedule of hole sizes for embedment of epoxy-set reinforcing dowels and threaded anchor rods was developed on the basis the writer's experience and was used for John Marshall High School with the results described above. It is offered with the caution that adequate performance is dependent on proper execution and selection of materials. It is also to be noted that performance of the type described in this paper is not recognized or allowed by any building code to our knowledge, and in order to properly use the method and the schedule, prequalification testing before use and proof testing of typical dowels or anchors continuously throughout the work is necessary. The working or allowable values for the anchors must be reduced to a level not more than 75 percent below the proof load values.

Grade 60 Rebar		35K Threaded Rod	
Size #	Hole Size (in.) Depth x Diameter	Size (in.)	Hole Size (in.) Depth x Diameter
#3	4-1/2 x 5/8	3/8	3 x 5/8
#4	6-1/2 x 3/4	1/2	4 x 3/4
#5	9-1/2 x 7/8	5/8	5 x 7/8
#6	10-1/2 x 1	3/4	6 x 1
#7	11-1/2 x 1-1/4	7/8	7 x 1-1/8
#8	14 x 1-3/8	1	8 x 1-1/4
#9	16 x 1-1/2	1-1/8	9 x 1-1/2
#10	19 x 1-5/8	1-1/4	10 x 1-5/8
#11	22 x 1-3/4	1-3/8	11 x 1-3/4
		1-1/2	12 x 2-7/8

QUALITY ASSURANCE

Certain quality assurance procedures, utilized on the John Marshall Project were requirements of the Office of the State Architect of California and the State Administrative Code, Titles 21, 22 and 24. They are also considered by the writer to be appropriate for any project, no matter what the jurisdiction, as they relate to the subjects covered in this paper, and are necessary to provide some certain knowledge as to the performance expected from materials and procedures that are special to such a project as this.

1. Concrete and Shotcrete:
   a. Mix designs for concrete and wet-mix shotcrete. Proportions for dry-mix shotcrete are generally considered to be empirical.
   b. Continuous placing inspection - essential for shotcrete.
   c. Sampling and testing of concrete cylinders.
   d. Extraction and testing of core samples from shotcrete as placed. Testing should include both compression and shear at the interface of shotcrete and brick.
2. Reinforcing Steel and Rod Anchor Material
   a. Testing of steel.
   b. Carbon equivalent determination of reinforcing to be welded.
   c. Continuous inspection of welding of reinforcing.
3. Dowel and Anchor Rod Installation.
   a. Qualification and proof testing as described above.