1. INTRODUCTION

Every earthquake has shown repeatedly that the buildings with the greatest natural resistance to damage are regularly shaped, one- or two-story, shear wall structures with their structural elements fully interconnected, and a minimum of special equipment and utility systems. It would be simple to say that all facilities that need to remain functioning after major earthquakes, such as hospitals, should be housed in these types of buildings. Unfortunately, this style of construction is completely incompatible with the delivery of health care. A balance needs to be purposely struck, therefore, between the functional and performance needs of hospitals and the available structural systems.
The multi-functional characteristics and changing needs of modern hospitals often demand multiistory buildings with highly irregular configurations, no interior structural walls, complex networks of utility and mechanical systems, as well as a wide variety of medical equipment and supplies. In order to provide for a functional level of performance following major earthquakes, there is a need for special design and construction procedures. The resulting facilities, while much more capable function following strong shaking, are somewhat more expensive to construct, compared to commercial structures designed to lower standards. Special consideration must be given to the building configuration, the structural system, the anchorage and bracing of architectural components, as well as all mechanical, utility, and medical systems. This can only be accomplished through a high level of interaction and coordination between the architects and engineers throughout the design.

2. ESSENTIAL STEPS TO IMPROVE THE SEISMIC PERFORMANCE OF HOSPITAL BUILDINGS

Unlike the seismic design process required to attain life-safety performance, achieving functionality requires persistent attention to detail. Every aspect of the structure, its systems and contents need to have proper earthquake resistance. For new hospitals buildings, the current California Building Code (CBC) requires the following essential attributes and steps to achieve this goal:

1. The structural systems of the building must be proportioned in such a manner that the amount of damage to the structure in a strong earthquake is minimized. Modern seismic codes emphasize the need for ductility, and this is an important attribute of any structure. However, in most structures, ductility (and the inelastic behavior that correlates with ductile action) equate to damage. In order to achieve the Immediate Occupancy performance objective, damage, and therefore ductility demand, must be limited. This is achieved through the selection, analysis, and design of a structural system that is complete, fully interconnected, redundant, ductile, and 50% stronger than required for conventional building construction. Special analysis procedures are required as well as additional strength if the structural system is irregular.

2. All nonstructural components, equipment and systems must be designed to resist seismic loading, as well as accommodate the displacements the building is expected to experience during a strong earthquake. To achieve this objective, the
design and detailing of appropriate seismic anchorage and bracing for all architectural elements, as well as for all mechanical, utility and medical systems and equipment. An added measure of safety can be obtained by providing back-up systems for essential elements.

3. Analysis and design of hospital structures is complex, and an independent review of the design and analysis procedures assures that the provisions of the building standards have been correctly implement. The independent review includes conducting a complete and comprehensive independent plan review of the entire design. The review may result in recommendations to modify the design as needed to meet code compliance and achieve the expected performance objectives.

4. Quality control of the construction process must be maintained. To achieve this, conduct full-time inspection throughout the construction process. Require the design professionals to visit the project during construction on a regular basis and verify the adequacy of the design and construction. Fully document all construction activities and develop a set of as-built drawings.

5. Monitor all remodel projects to assure that they do not reduce the seismic resistance of the existing building and that they are constructed to the same seismic resistant standards.

3. PURPOSE AND PHILOSOPHY OF THE ENFORCEMENT AGENCY

Pursuant to the Hospital Seismic Safety Act, OSHPD is responsible for overseeing all aspects of general acute care hospital, psychiatric hospital, and multi-story skilled nursing home and intermediate care facility construction in California. This responsibility includes:

1. Establishing building standards which govern construction of these types of facilities;

2. Reviewing the plans and specifications for new construction, alteration, renovation, or additions to health facilities; and,

3. Observing construction in progress to ensure compliance with the approved plans and specifications.

OSHPD’s responsibilities under the Hospital Seismic Safety Act are carried out by the Facilities Development Division (FDD). FDD serves as a "one-stop shop" for all aspects of health facility construction. All geo-technical, structural, mechanical, electrical and fire/life safety considerations for inpatient healthcare facility physical plant are handled by FDD. To accomplish its mission, FDD has divided the state into six geographic regions. Each region is supported by an office staff, which provides in depth plan review services and a field staff, which observes construction. These regions are managed from a central office located in Sacramento, California. The FDD oversight process entails the following:

1. Design drawings and specifications are submitted to FDD and reviewed for code
compliance by division architects; structural, electrical, and mechanical engineers; 
and, fire and life safety personnel. Upon plan approval, a building permit is issued 
and construction begins.

2. Once construction begins, the FDD field staff assumes responsibility for 
construction oversight. During this process, a District Structural Engineer 
observes progress on the structural aspects of the project, all Fire and Life Safety 
issues are observed by a Fire/Life Safety Officer and an Area Compliance Officer 
monitors progress on mechanical, electrical and architectural aspects. These field 
personnel can only make periodic visits to the construction site. Therefore, each 
hospital owner is required to hire an FDD certified Inspector. This inspector is 
required to provide continuous inspection of all parts of the work. The inspector 
works in close coordination with the design professional, the owner, and the FDD 
staff to ensure that the project is constructed in conformance with the approved 
plans and specifications.

FDD staff also play an important role in the aftermath of an earthquake. Staff are dispatched 
to assess the extent of damage to health facilities in the affected communities. Based on 
these assessments, the facilities are cleared to continue providing care without interruption 
or, access to some areas of the facility may be restricted due to local damage, or, if the 
damage is severe enough, the facility may be closed. The results of these assessments are 
communicated to state and local emergency response personnel, so they can route patients 
to safe facilities. As well, FDD staff review and approve on-site construction required for 
mitigation of earthquake damage to the facility.

Post-earthquake repairs are reviewed by OSHPD. The level of required repair depends on 
the severity of the damage the building sustained. Buildings that have suffered substantial 
damage may require reconstruction to current code standards.

4. CODES & STANDARDS

4.1. General

OSHPD/FDD enforces building standards published in the California Building Standards 
Code relating to the regulation of health facilities construction projects. The Office adopts 
these building standards which are published in the model code (i.e. Uniform Building 
Code, National Electrical Code, Uniform Mechanical Code, Uniform Plumbing Code and 
the Uniform Fire Code) and which are modified extensively with California amendments to 
meet the performance requirements established by the HSSA. The California Building 
Code is the Uniform Building Code with the California amendments. The latest edition of 
California Building Code (CBC) was published by the International Conference of Building 
Officials in 1998.

4.2. Building Code Adoption

The State Building Standards Law requires that state agencies proposing changes to 
building standards (new, amendments to existing, or repeal of existing standards) submit
proposals to the California Building Standards Commission (CBSC) for adoption consideration during the annual code adoption cycle. The California amended version of the model code is adopted by the CBSC through an administrative law adoption process which requires public notice and allows public participation.

The required steps in the code adoption process are as follows: When the annual code adoption cycle begins the state agencies submit code changes to the CBSC for review and acceptance. The code change submittals are reviewed by the CBSC’s selected Code Advisory Committees for technical review and recommendations to the CBSC. The code changes are then noticed to the interested public to allow review and comments. The last phase of the annual code adoption cycle is the CBSC’s approval and adoption of the proposed code changes. Proposed changes are generated in a number of different manners. Representatives of professional organizations, industry groups, and other interested parties may suggest changes or enhancements to model code. Recommendations or procedures from other technical sources or research may be incorporated into the California Amendments. The result is a set of state-of-the-art design codes.

4.3. Ground Motion Requirements

Chapter 16 of the CBC presents methods for determining earthquake shaking demands and considering other seismic hazards such as liquefaction and landsliding. Earthquake shaking demands are expressed in terms of ground motion response spectra, discrete parameters that define these spectra, or pairs of ground motion time histories, depending on the analysis procedure selected. These parameters are presented in a site-specific geotechnical report prepared for each construction project.

4.4. Design Earthquake

The seismic hazards levels of Title 24 CBC are defined on a probabilistic basis. The basic design is based on ground motion hazard levels generated by the “maximum probable earthquake” (design basis earthquake). The “maximum probable earthquake” ground motion is defined as the motion having a 10 percent probability of being exceeded in a 50-year period (474 years mean return period). This is the same ground motion as that defined in the UBC. Where more detailed analysis methods are required (i.e. dynamic analysis) the structure(s) under consideration must be designed to resist two levels of earthquake hazards. In this situation the structure must be designed to resist the maximum probable earthquake ground motion and in addition it must be demonstrated that the structure can also sustain the upper bound earthquake motion, including P-Δ effects without forming a story collapse mechanism. The “upper bound earthquake” ground motion is defined as the motion having a 10 percent probability of being exceeded in a 100-year period (950 years mean return period).

4.5. Criteria for New Construction

The Title 24 CBC permits two methods to be used.
in determining the seismic loading: Static Force (SF) Procedure and Dynamic Force (DF) Procedure. The Title 24 CBC is very specific about when the static force procedure can be used. In general, any structures may be designed using the dynamic force procedure at the option of the structural engineer, and some structures must use the dynamic force procedure. Although a static force-based design approach is acceptable for small regular buildings, larger buildings, particularly those with irregularities need more advanced analysis. Performance based design techniques, featuring nonlinear analysis procedures and limits on individual component damage are being developed. Although not in wide use, such techniques are currently being used for retrofit of existing buildings, and will probably be introduced into codes soon.

The majority of the structures under OSHPD jurisdiction are designed by the SF Procedure and therefore are designed to resist ground motion levels generated only by the maximum probable earthquake. In the SF Procedure, the effects of the ground motion are represented by the quantity $Z_C$ along with an importance factor of $I=1.5$. The seismic zone factor, $Z$, accounts for the amount of seismic risk present in the seismic zone where the subject building is located. The CBC defines the seismic zone factors and the boundaries for each of the zones. The value $Z$ is intended to represent the Effective Peak Ground Acceleration (EPA) that will be generated by the maximum probable earthquake. The quantity $C$ represents the dynamic amplification factor. The effects of the soil characteristics on the ground motion characteristics at a building site are considered through the site coefficient $S$. The value $S$ is determined from the soil profile underlying the building site. The CBC defines four soil profiles. Generally the value of $S$ varies from 1.0 to 1.5. In special cases (soil profile $S_4$ - soft sites, i.e. bay mud), the value of $S$ may equal to 2.0. The site coefficient, $S$, is included in the calculation of $C$ to adjust the curve shape to the appropriate frequency response content for the site soil characteristics.

For complex or irregular structures the seismic loading must be determined by the dynamic force procedure. The ground motion for the dynamic analysis may be in the form of response spectra or time histories. When response spectrum dynamic analysis is used to determine the seismic load for regular structures, the standard site dependent spectra (smoothed average normalized 5% - damped response spectra) furnished by the CBC in Figure 16A-3 may be used. For irregular structures and all structures located on soil profile $S_4$ the ground motions used in the dynamic analysis must be site specific response spectra or appropriate pairs of time histories scaled to match the site specific response spectra. The CBC requires that the minimum design base shear resulting from the dynamic analysis must be:

1. Regular buildings....... 100% of the base shear value determined from the static method.
2. Irregular buildings...... 125% of the base shear value determined from the static method.

When the base shear from the dynamic analysis is less than these values it must
be scaled up to these values. In addition, the CBC allows where site specific ground motions are used for dynamic analysis and the seismic hazard level exceeds that of the code, the maximum resulting base shear for design need not exceed the base shear value determined from the static method scaled by the Spectral Ratio quantity SR.

4.6. Seismic - Isolated Structures

The CBC requires in general seismic-isolated structures to be designed using the Dynamic Lateral-Response (DLR) Procedure. The Static Lateral-Response (SLR) Procedure must be used to establish minimum criteria only, and not be used for design purposes unless these minimum requirements exceed calculated values from the DLR procedure.

In the SLR Procedure the ground motion for design is reflected by the EPA coefficient Z (as a measure of ground shaking level), the site coefficient S (to account for the effects of the local soil profile) and the near source factor N.

For the DLF Procedure either response spectrum or time-history analysis methods are employed utilizing ground motions that reflect the effects of the local seismicity and soil site conditions.

Where the response spectrum analysis method is utilized, the CBC requires the site-specific design response spectra for the DBE and the MCE not be less than 80% of the normalized response spectrum given in Figure 2 for the appropriate soil type at the building site, scaled by the product ZN and \( M_M \)ZN respectively.

Where time history analysis is utilized, the CBC requires that the design shall be based on either, the maximum of the results of not less than three separate analyses each using a different pair of horizontal time histories, or the average of seven separate time history analyses. Each pair of time histories shall:

1. Be of a duration consistent with the magnitude and source characteristics of the DBE or the MCE;
2. Incorporate near field phenomena as appropriate;
3. Have response spectra whose SRSS combination of the two horizontal components equals or exceeds 1.3 times the “target” spectrum at each spectral ordinate, and;
4. Have the SRSS of the time history components equal to or greater than the 5% damped response spectra at the period of the isolated structure, \( T_1 \).

4.7. Nonstructural Components

The FDD has always placed a high

Fig. 4: Non structural damage
priority on the performance of nonstructural components. Failure of these systems can result in closure or evacuation of a hospital building even though the lateral-force-resisting system has received little or no damage during the seismic event. During the Northridge Earthquake the Los Angeles County Hospital in Sylmar, that replaced the structure that collapsed during the 1971 event, had insignificant damage to the structural system, but flooding due to a failure in a chilled water return line, fire sprinkler head damage, and a loss of "lifeline" water forced the evacuation and transfer of patients to other facilities. Damage such as this made it difficult for facilities to meet the intent of the HSSA that hospitals, "... must be reasonably capable of providing services to the public after a disaster. This performance goal is a significant step above the stated objective of the Uniform Building Code.

The basic formula for determining the horizontal force \( F_p \) is \( F_p = ZI_pC_pW_p \) (1.1)

where \( Z, I_p, \) and \( W_p \) are the seismic zone factor, component importance factor, and weight of the component, respectively. The value of \( C_p \) varies depending upon the component behavior. In general, this formula generates design lateral forces of between 0.5g and 1.0g in regions of high seismic risk. The variations in design force are the result of consideration of element flexibility, the strength and ductility of the component anchorage.

In addition to being able to resist the inertial forces generated by the earthquake, nonstructural components must withstand the story drifts the building will experience during strong ground shaking. Components and systems that run from floor to floor or building to building must be designed to accommodate the differential movements expected. These movements are computed at the actual shaking levels, not reduce levels used for proportioning components of the lateral force resisting system.

OSHPD has supported programs to standardize the anchorage and bracing of nonstructural components found in typical hospital buildings. This process helps to control construction costs and speed the review process. Manufacturers of equipment, components, and bracing systems may participate in the Anchorage Pre-Approval Program. In this program, the vendor provides standard anchorage and bracing drawings, and supporting calculations for review by OSHPD. The details must cover typical installations of the system or component. Pre-Approvals are valid for a period of three years. When a component or system is installed in accordance with the pre-approval, office plan review of the anchorage is waived.

5. PLAN REVIEW

All hospital and skilled nursing facilities undergo a detailed plan review process. The purpose of the plan review is to validate the design and analysis methodology chosen by the building designer, and to confirm that the provisions of California Building Code are properly applied.

New projects are often given a preliminary review, while the project is still under design. This provides the design professional the opportunity to review fundamental design and analysis procedures with OSHPD before the major design decisions are finalized. Potential areas of concern, such as unusual configuration of the structural systems, special site
conditions, or alternative methods of construction or analysis may be reviewed at this time.

Projects received for plan review are initially triaged. Incomplete submittals are returned to the designer for further work. Complete project are accepted for review. Plan review comments are made directly on the drawings. Standardize comments, which cover the typical areas of concern, are used as often as possible. The marked-up set of drawings and specifications are returned to the design professionals for correction. The design professional submits a corrected design package for back-check. Additional cycles of review and back-check are performed as needed. Upon completion of the review, an approval letter is issued, and the hospital owner may apply for a building permit.

OSHPD review focuses only on building design issues. Environmental reports, zoning, and planning issues are resolved at the local level.

6. CONSTRUCTION OBSERVATION AND QUALITY CONTROL

Once a building permit has been issued, the project proceeds to construction. The facility owner retains an Inspector-of-Record (IOR). The IOR acts as the owners agent, assuring that the building is constructed in accordance with the design drawings and applicable codes and standards. The IOR often oversees the work of other inspectors, each trained to review construction specialties, such as concrete placement and welding. The design professionals, IOR, and inspectors must keep written records of their observations, and submit regular reports to OSHPD.

OSHPD provides construction advisory services during the building process. Both structural engineers and construction advisors make regular visits to the jobsite, reviewing progress on the work, and processing change-orders and construction buildings that arise during the course of the job. These individuals can handle most field conditions arising during the project. Extensive or complex changes to the work are forwarded to an OSHPD office for review and approval.

7. CONCLUSION

For the past 28 years, California’s hospital seismic safety program has striven to improve the safety of hospital patients, and help insure that hospitals will be able to care for the injured following strong earthquakes. The program has evolved over the years, in response to the changing needs of the people of California, and to adopt lessons learned in earthquakes. Recently, the SB 1953 program was established to reduce the risks posed by buildings constructed prior to the Hospital Seismic Safety Act. By focusing on all aspects of hospital design and construction, the program has produced buildings that have proven far more survivable than structures built to typical building standards. The program will continue to evolve as new information and technologies become available.

8. REFERENCES


