SEISMIC DESIGN CRITERIA FOR SAN FRACISCO WATER SYSTEM IMPROVEMENT PROGRAM

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ABSTRACT:

The San Francisco Public Utilities Commission (SFPUC) manages a water system stretches from the Sierra Nevada Mountains to San Francisco. The system was built in the early to mid 1900's; many parts of this system are nearing the end of their working life. In addition, crucial portions of the system cross over or near three major earthquake faults in the Bay Area. The SFPUC, together with its 28 wholesale customers, launched a $4.3 billion Water System Improvement Program to repair, replace, and seismically upgrade the system's aging pipelines, tunnels, reservoirs, and dams. A major component of the program is the seismic improvement of the system. To meet the level of service for seismic recovery, general seismic requirements for design of new facilities and upgrade the existing facilities were developed. This paper provides an overview of the SFPUC seismic design criteria. It includes (1) general issues on level of service, performance goals and seismic performance classes, (2) seismic hazards, (3) design earthquakes, (4) criteria for various structures such as buildings and building-like structures, pipelines, soil retaining structures, underground structures, water retention structures, dams and reservoirs, and reservoir outlet towers.

KEYWORD: design criteria, seismic design, water system, lifeline, San Francisco

1. INTRODUCTION

The San Francisco Public Utilities Commission (SFPUC) manages a complex water supply system stretching from the Sierra to the City of San Francisco and featuring a complex series of reservoirs, tunnels, pipelines, and treatment systems (Figure 1). Two unique features of this system stand out: the drinking water provided is among the purest in the world; and the system for delivering that water is almost entirely gravity fed, requiring almost no fossil fuel consumption to move water from the mountains to the customers.

The SFPUC, the third largest municipal utility in California, serves 2.4 million residential, commercial, and industrial customers in the San Francisco Bay Area. Approximately one-third of delivered water goes to retail customers in San Francisco, while wholesale deliveries to 28 suburban agencies in Alameda, Santa Clara, and San Mateo counties comprise the other two-thirds of the deliveries.

Fig. 1 SFPUC Water System

Built in the early to mid 1900's, many parts of the system are nearing the end of their working life. In addition, crucial portions of the system cross over or are near three major earthquake faults in the Bay Area. The SFPUC, together with the San Francisco Bay area 28 wholesale customers launched a $4.3 billion Water System Improvement Program (WSIP) to repair, replace, and seismically upgrade the system's aging pipelines, tunnels, reservoirs, pump stations, storage tanks, and dams. The program will deliver the key goal and levels of service for seismic recovery through more than 75 San Francisco and regional projects, to be completed by the end of 2015. The WSIP is funded by a bond measure that was approved by San Francisco voters in November 2002 to repair, replace and seismically upgrade the Hetch Hetchy water system.

Because the SFPUC water system consists of various types of structures as mentioned in the previous paragraph, guidelines are needed to provide a uniform design baseline. A seismic design criteria document titled *SFPUC General Seismic Requirements for Design of New Facilities and Upgrade of Existing Facilities* (SFGSR) was developed. The document is divided into 12 chapters plus the references. They are (1) general issues on level of service, performance goals and seismic performance class, (2) site criteria, (3) buildings, (4) underground and aboveground piping, (5) soil retaining structures, (6) underground structures, (7) water retention structures, (8) dams and reservoirs, (9) special structures such as reservoir outlet towers and pumping plants, (10) equipment, and (11) general framework for seismic evaluation and rehabilitation of existing facilities. There are also three appendices: (1) faults and seismicity in the region including SFPUC facilities, (2) geologic, landslide, and/or liquefaction maps, and (3) probabilistic fault rupture hazard analysis.

Performance goals and classes, geotechnical hazards, design earthquakes, and highlights of design criteria for different structures are discussed in the following sections.

2. PERFORMANCE GOALS AND CLASSES

The SFPUC has committed to a basic "Level of Service Criteria" which is to be able to deliver winter day demand (WDD) of 215 million gallons per day with 24 hours after a major earthquake. This is based on the assumptions that (1) deliver WDD at least 70% of SFPUC wholesale customer's turnouts within each of the three customer groups (Santa Clara/Alameda/South San Mateo County, Northern San Mateo County, and City of San Francisco) and (2) achieve a 90% confidence level of meeting the above goal, given the occurrence of a major earthquake. To verify achievement of the service performance goals, the SFPUC will perform periodic remodeling of the SFPUC system using updated fragility data.

A new terminology "Seismic Performance Class" (SPC) is introduced. Numerical numbers of I, II, and III are assigned according to the criticality of the structure. SPC with expected performance goals and examples are described in Table 1.

Table 1 Performance Goals and Seismic Performance Class

Performance Goal	Seismic Performance Class	Potential Examples [1]
Provide life safety protection for major earthquakes likely to affect the site. Facility may not be economically repairable in the event of such an event.	**Standard** **I**	• Administrative centers, repair shops, service centers and similar support facilities. Repair shops needed for post earthquake repairs may need to be in a higher Seismic Performance Class.
Provide life safety protection for earthquakes likely to affect the site. Facility may experience damage but should be capable of restoration to service within 30 days.	**Important** **II**	• Structures and components of the storage, distribution, treatment and control systems with some level of redundancy or for which failure does not result in an unacceptable service level. • Pressure zones with pumping plants, reservoir sites and the like providing redundancy and having no common-cause failure modes[2], shall have their facilities classified as Important, but should be capable of restoration to service within a specified period of time. (The required recovery time for these facilities will be determined by the project-specific requirements.)
Provide life safety protection for earthquakes likely to affect the site. In addition, provide reasonable expectation of post-earthquake operability. Facility should be capable of restoration to a level of service consistent with adopted post-earthquake Level of Service goals within 24 hours.	**Critical** **III**	• Structures and components of the storage, distribution, treatment and control systems with no redundancy or with redundancy having common-cause failure modes[2], and the failure of which results in an unacceptable service level. • Facilities located in pressure zones (or parts thereof) having no redundancy or redundancy with common-cause failure modes, are classified as Critical. Attention must also be given to flow limitations within the pressure zone when assessing redundancy. • Facilities needed for emergency response, such as emergency operations centers and emergency repair/response centers.

In order to facilitate the use of the criteria document, a suggested seismic design process is summarized in the flowchart shown in Figure 2.

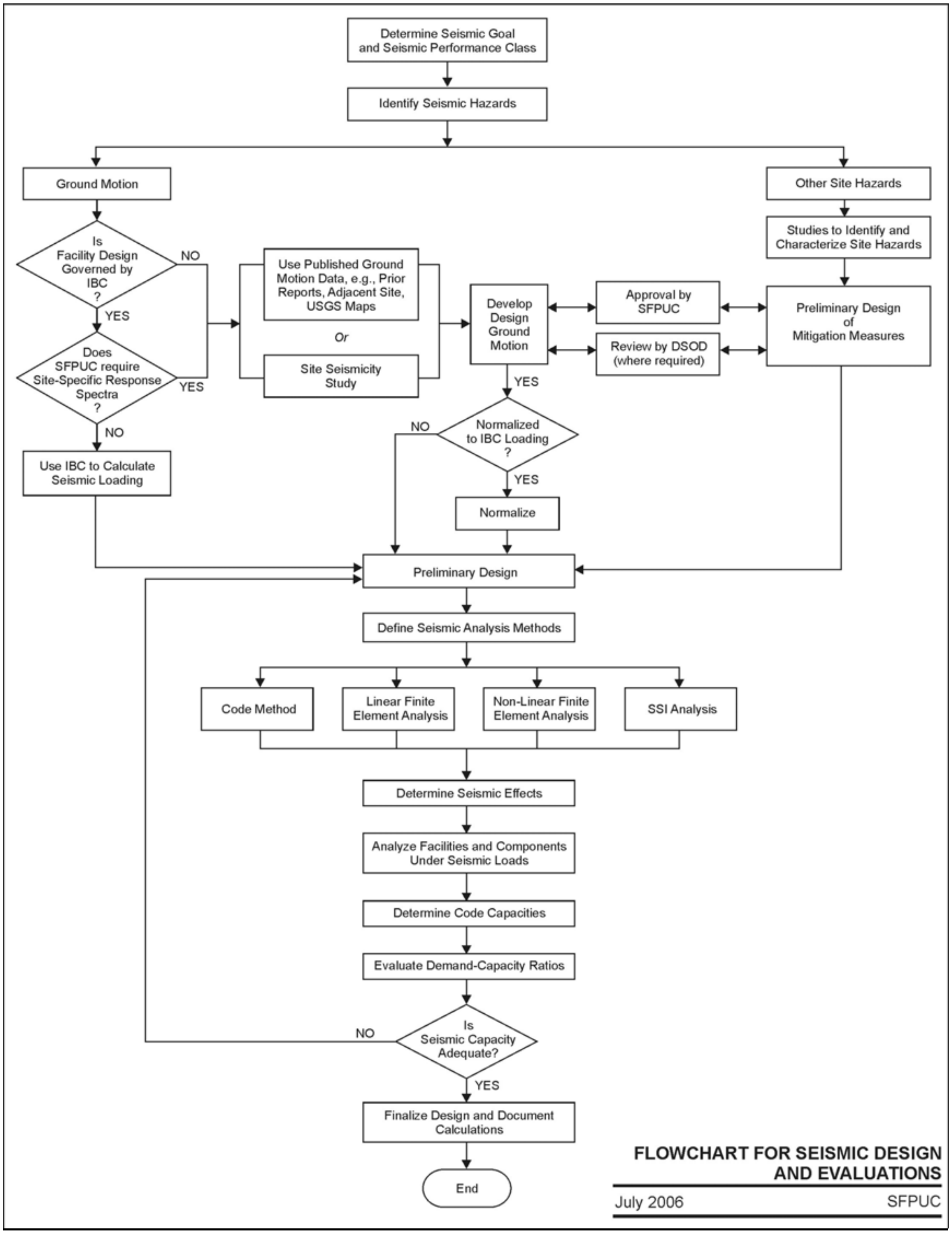

Fig. 2 Flowchart for Seismic Design and Evaluation

3. SEISMIC HAZARDS

The SFPUC facilities are located in an area where the level of seismicity is one of the highest in California. Figure 3 shows active faults, secondary faults and potentially active faults within the SFPUC water system. The hazards associated with such potential seismic activity include:

- Fault rupture at site traversed by faults;
- Ground motions generated by earthquakes occurring on nearby or distant faults;
- Instability of slopes at or near the site;
- Liquefaction, in saturated cohesionless soil strata underlying the site of a facility, that may lead to loss of bearing for shallow foundations, lateral support of deep foundations, settlements, lateral spreads and/or lateral flows, and buoyancy effects;
- Loss of strength in cohesive soil strata underlying a facility that may lead to comparable consequences.

Some of these hazards need to be identified and evaluated on an area or system-wide basis and some require site-specific investigations. Evaluation of fault activities and the potential for fault rupture across a facility and estimation of earthquake ground motions generated for a generic site condition (e.g., rock outcrop) need to be performed on an area or system-wide basis. The other hazards, including estimating earthquake ground motions to account for a local site condition, instability of slopes, liquefaction of saturated cohesionless soils, or loss of strength of cohesive soils require site-specific investigations.

To complete these hazard evaluations, the SFGSR requires a study including geologic, seismologic, and geotechnical aspects.

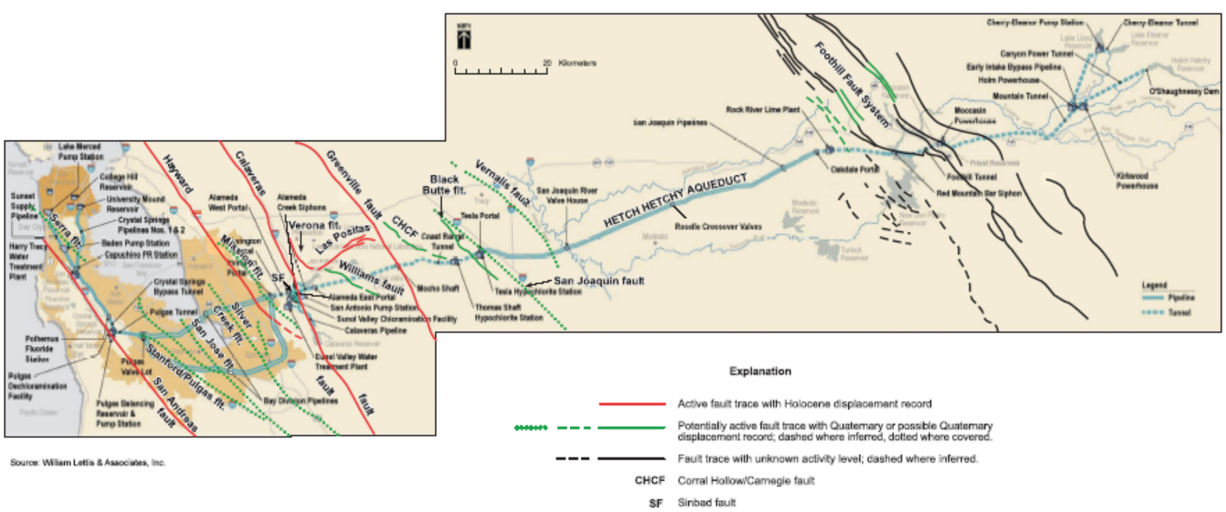

Fig. 3 Schematic Fault Map of the SFPUC Water System

4. DESIGN EARTHQUAKES

Because the SFPUC water system includes many different types of structures such as treatment plants, pump stations, vaults, valve houses, pipelines, tunnels etc., design earthquakes are different for each facility.

For the design of new structures such as buildings, building-like structures (defined as a structure which has vertical and lateral systems similar to buildings and is designed, fabricated and erected in a manner similar to buildings), tanks, vaults, treatment/filter basins, equipment anchorage, and any other structures covered in ASCE/SEI 7, the design earthquakes should be the ground motions as described in IBC which is based on a Maximum Considered Earthquake (MCE) modified with appropriate design parameters.

For the rehabilitation of existing structures, the design earthquakes should be the ground motions as defined in ASCE/SEI 41. They are Basic Safety Earthquake 1 (BSE-1) and Basic Safety Earthquake 2 (BSE-2). They can be defined on either a probabilistic or deterministic basis. The SFGSR defines BSE-1 as an earthquake with a level of ground shaking having a 10% probability of exceedance over a 50-year interval (475-year return period earthquake) and BSE-2 as one with a level of ground shaking having a 2% probability of exceedance over a 50-year interval (2475-year return period earthquake). When the MCE maps do not adequately characterize the local hazard, site-specific procedures should be used.

For the assessment of seismic geozards and the design of pipelines and tunnels, the design earthquake ground motions should be determined by probabilistic procedures. Pipelines and tunnels in SPC I and SPC II should be designed to resist the 475-year return period earthquakes. SPC III pipelines and tunnels should use the 975-year return period earthquakes. The design earthquake need not exceed a deterministic limit taken as the 84^{th} percentile level earthquake on San Andreas, Hayward, and Calaveras faults.

5. DESIGN CRITERIA FOR VARIOUS TYPES OF STRUCTURES

5.1 Buildings and Building-like Structures

Design of new buildings and building-like structures should follow the provisions in IBC and ASCE/SEI-7. An Occupancy Category I or II, III, and IV shall be assigned to facilities with SPC I, II, and III, respectively.

Existing buildings and building-like structures should first be evaluated by using ASCE 31. If the structure is found to be inadequate to resist the prescribed earthquake forces, it needs to be seismically upgraded in accordance with its SPC classification and applicable ASCE-41 provisions. The structure has to meet certain performance criteria to resist the two levels of earthquake as described in the criteria document. For example, under a BSE-I earthquake, a SPC III structure should be rehabilitated to the Immediate Occupancy Level for structural elements and to the Operational Performance Level for non-structural elements; and under a BSE-II earthquake, the same structure should be retrofitted to the Immediate Occupancy Level for both structural and non-structural elements.

5.2 Pipelines

Pipelines may be designed by ALA Guidelines (ALA, 2005) except as modified by the SFGSR. SPC I pipelines are normal and ordinary small diameter distribution pipelines. SPC II pipelines are critical pipelines serving a large number of customers that present significant economic impact to the community or a substantial hazard to human life and property in the event of failure. SPC III pipelines are essential pipelines that are required to remain functional and operational after a design earthquake.

Pipeline fault crossing design can be the following three basic types: (a) avoid crossing the fault, if possible; (b) design the pipe to accommodate fault offset without failure of the pressure boundary; (c) provide suitable valves and manifolds and bypass pipe to allow rapid restoration of water service across the fault zone, should the pipe fail at the fault. A combination of (b) and (c) may be recommended in some situations.

5.3 Soil Retaining Structures

Soil retaining structures should be designed for appropriate static and seismic soil pressure depending on the restraining conditions of the wall. Where applicable, the effects of hydrodynamic loads shall be considered.

5.4 Underground Structures

Tunnels require special 2-D or 3-D soil-structure interaction analysis depending on the structure layout and dimensions. Seismic responses of underground structures are controlled by ground deformation instead of forces. Some references on the design and analysis are provided in the criteria document. These techniques permit development of an optimal design that wound conform to ground deformation without attracting large seismic loads.

Vault walls should be designed for appropriate soil pressure similar to soil retaining structures. The embedded vault structures should be investigated for potential liquefaction and buoyancy effects.

5.5 Water Retention Structures

Tanks and vessels should be designed in accordance with ASCE-7. The modifications applicable to on-grade steel tanks, elevated steel tanks, and concrete pedestals tanks are given in the criteria. The evaluation of existing tanks should be based on ASCE-7, AWWA, ACI and ASCE-41 with appropriate modifications applicable for tanks.

Covered water retention basin structures have similar vertical and lateral systems to buildings. Criteria for building-like structures in addition to ACI350 and AWWA are applicable to design new and rehab existing covered basin structures. Open roof, water retention basins should be designed in accordance with ACI350 with the SFGSR modifications.

5.6 Dams and Reservoirs

Dams and reservoirs in California are under the jurisdiction of the California Department of Water Resources’ Division of Safety of Dams (DSOD). They should be designed following the guidelines by the DSOD and the United States Society of Dams (USSD). Applicable DSOD and USSD design guides are listed in the SFGSR.

5.7 Special Structures

Design guidelines for reservoir outlet towers are covered under the criteria for special structures. Because outlet tower is considered as an essential part of a dam structure, it needs to meet much stringent requirements. Dynamic analysis using a 3-D finite element model is required. Evaluation and design methods outlined in UASCE EM 110-2-2400 are recommended.

For structures not mentioned in the criteria document, project specific requirements will be developed using the most updated and acceptable procedures from the recognized experts.

6. CONCLUSIONS

The goal of the SFPUC seismic criteria is to meet the performance goal of providing water to majority of the customers in a short time after a major earthquake. The criteria for design of new structures and rehabilitation of existing facilities in the SFPUC water system improvement program are in accordance with the latest codes and standards with the supplements of most reliable updated information. For structures not covered by codes or standards, the criteria rely on most widely accepted published papers and reports with input from experts.

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