VII. NONSTRUCTURAL DAMAGE AND ITS EFFECT ON HOSPITAL FUNCTION

a. Structural and Nonstructural Damage:

At the time of the San Fernando earthquake the intent of the seismic building code was to limit damage to ensure against structural collapse, and consequent life loss and injuries. Hence the code only dealt with building structure, and had no provisions directed to building service systems, equipment, or architectural elements whose damage might result in economic or functional loss. The one exception is that of fire-sprinkler systems: these were installed according to the requirements of NFPA Standard 13, which specified lateral bracing to the structure, and flexible couplings where pipes passed through floor slabs and walls. Performance of these systems in the San Fernando earthquake was excellent and less than 4% of the 973 sprinklered buildings in the area of heavy shaking suffered "slight-to-severe damage" to sprinkler systems (5). Since the San Fernando hospitals had been built at different times, and were subject to an evolving code, their effectiveness varied even in preventing structural damage, and in the case of some of the buildings at the Veterans Hospital, built before the seismic code came into existence, seismic design was non-existent, with tragic consequences.

The great damage to nonstructural components in the San Fernando earthquake, particularly in hospitals, forced the realization that the conventional structural seismic code approach was inadequate in protecting such essential buildings, which because of damage to nonstructural components might have their use severely impaired during the minutes and hours when they were most needed. Consequently, in California the Hospital Act of 1977 was enacted into law, which required that all new hospitals be designed and constructed to remain functional for all essential services after an earthquake. The Veterans Administration introduced a similar requirement directing that all V.A. hospitals in seismic zones be designed to remain functional for four days after an earthquake independent of outside services. The methods by which these aims were to be achieved depended on increasing the force levels to which the main building structure is designed and, for the first time, imposing seismic force requirements on the design of critical service equipment and distribution systems.

There need be little doubt that the methods proposed will significantly reduce both structural and nonstructural damage, and consequent loss of function, in those buildings designed according to these standards. This is, however, still a relatively small percentage of the hospital facilities in seismic zones: most patients and staff are housed in buildings designed some time during the evolution of the structural code, and prior to the enactment of the Hospital Act. So an indication of the effects of the earthquake on nonstructural components, systems, and equipment, remains an important issue in determining methods of improving functional resistance of the existing hospital. In particular, a realistic assessment of economic and functional expectations is necessary to determine what measures an institution may wish to take for its own safety and economic benefit. Retrofitting to the level of the Hospital Act is a very expensive and time consuming proposition, and it is safe to say that no institution will voluntarily wish to undertake such a program: if something less is to be done, what measures will provide the best return for the best investment?

Two further points about nonstructural damage need to be made. First, nonstructural damage is only significant if the building does not collapse: when the building collapses issues of function and assessment of nonstructural damage are moot: the critical needs are to aid the trapped and injured and to evacuate occupants from parts of the building that have not suffered complete collapse. So in the tables that follow we find little information from the Veterans Hospital because of the complete collapse suffered by two occupied buildings.

The second issue is that, having made the distinction between structural and nonstructural damage, it is necessary to look more closely at the interactions between structural and nonstructural components, and not be too hasty in assuming the extent to which nonstructural damage occurs independent of structural damage.

Nonstructural damage occurs in two ways: the first is through direct vibration, transmitted from ground motion through the building structure to a nonstructural component. The second cause of damage is when fracturing or distortion of a structural element causes damage to an attached or adjoining nonstructural component. There is, thus, a distinction between, say, an interior ceramic tile facing which falls from a backing wall because its adherence fails (direct vibration cause) and tile which fails because the structural backing cracks (damage to structural element). To the extent that nonstructural damage is of the latter type we can say that the nonstructural damage originated in structural failure and measures that reduce the possibility of structural damage also reduce the likelihood of nonstructural damage. Moreover, such nonstructural damage may not be only the result of structural failure but may also be the result of the correct working of the structural energy absorption process. Thus horizontal members of the steel structure may be designed to distort under loads, absorb energy, and prevent total failure of vertical load bearing members. But in so doing, they may cause extensive nonstructural damage to facing or adjoining nonstructural components.

b. Nonstructural Damage: unanswered questions:

Although the extent of nonstructural damage to buildings in the San Fernando earthquake was widely noted, and one detailed engineering study was published on damage to mechanical and electrical services and equipment (6), little systematic evaluation was done of the consequences of such damage. Nor was any systematic listing of nonstructural damage done; although some institutions prepared detailed lists of such damage for reimbursement or insurance purposes, the information is unrealistic, often not distinguishing between equipment which was damaged and that which was lost by removal.

From interviews with staff it is possible to obtain a reasonably reliable description of the consequences to hospital services and function, and this picture is summarized in Tables II through VI, which refer to the major essential hospital services. Appendix II provides a more detailed listing of damage to nonstructural components and contents in one hospital.

The five hospitals surveyed in this study were reinforced concrete, or reinforced concrete frame and infill structures, designed with little provision for ductility i.e. the ability to suffer considerable deformation before collapse. With the exception of the V.A. hospital, none suffered complete collapse, and since they were stiff non-ductile structures major nonstructural damage was due primarily to direct vibration rather than structural distortion. An exception to this can be seen in the two lower floors of Olive View Hospital where the structure of the soft story did perform in a ductile manner and suffered great distortion, far beyond the intended performance of the structure.

One result is that any conclusions must be limited to the performance of these types of structures: hence we still lack conclusive experience of the nonstructural performance of ductile steel frame structures, particularly of the common high tower/broad base type common in hospital design. We may anticipate more movement (deflection) and more structural distortion, under heavy loads, in these buildings, with consequent greater nonstructural effects.

Although detailed evidence is not available, it appears that little injury, and no deaths, were caused by the extensive nonstructural damage at the San Fernando hospitals. The reasons for this must be a subject for speculation. First, nonstructural damage of the type encountered in these hospitals is primarily that of equipment moving around, shelves and their contents toppling, and partitions fracturing but not collapsing. One can hypothesize that even for an immobile occupant (a patient in a bed) the probability of being hit and severely injured by a heavy item is fairly low.* Further, that anyone who is capable of movement will tend to have an instinctive protective reaction during the shaking that may be enough to provide protection to vulnerable parts of the body from items such as shelves and equipment. In addition, people have time to move away from items which show, through their movement, that they are liable to collapse.

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* T.V. sets in patient rooms at Pacoima hospital were 'catapulted' off their mounts, but no patients were injured. Without knowing how many T.V.s fell off, and how many beds were occupied, it is hard to draw conclusions.

The potential for serious injury from nonstructural components is clearly there: it is a deficiency in our research of this problem that we lack definitive data, with the result that we currently tend both to under react - do nothing - and over react - attempt to rigidly attach every nonstructural item to the structure. The conceptual answer to the nonstructural problem would appear to be a program that combines occupant training in protective behavior, structural attachment and structural isolation.

DAMAGE TO BUILDING SERVICES	ELEVATORS
OLIVE VIEW:	. elevators inoperative due to power failure and building distortion. . elevator doors jammed.
PACOIMA:	. all 3 elevators disabled. . elevator fixed during first day by elevator company, used to remove heavier items of equipment. . 10:00am engineering department decided one elevator safe, used to evacuate critical patients. . elevators depend on emergency power, so intermittent operation only.
HOLY CROSS:	. elevators inoperative due to counter weights leaving tracks and tangling cables. . steel guides bent.
V.A., SAN FERNANDO:	. no information noted: not significant since buildings totally evacuated.
KAISER, PANORAMA CITY:	. all 6 elevators out of action for 24-36 hours. . one elevator still out March 1. . elevator repairs cost $44,000.

TABLE II

DAMAGE TO BUILDING SERVICES	POWER
OLIVE VIEW:	• lost power due to damage to incoming lines. • all floors lost power. Power restored in two days to some buildings. Main building never had power restored. • damage to emergency generator, and collapse of unanchored batteries results in failure of emergency power system.
PACOIMA:	• power generators knocked off platform. • many electrical conduits damaged. • power out for 1/2 hour after Q, then emergency came on: adequate but intermittent.
HOLY CROSS:	• all power off. • emergency generators knocked out. • emergency power was established after 2 hours.
V.A., SAN FERNANDO:	• building housing central power supply collapsed: all power off.
KAISER, PANORAMA CITY:	• city power off for about 20 minutes. • emergency power remains functional.

TABLE III

DAMAGE TO BUILDING SERVICES	COMMUNICATIONS
OLIVE VIEW:	. telephone equipment in basement of main building damaged. . no telephones; no communication in or out of hospital for first hours. . off duty motorcycle patrolman established communication.
PACOIMA:	. telephone switchboard fallen off mount and sitting in middle of lobby. . telephone service remained for about half-hour after Q then went off. later became intermittent.
HOLY CROSS:	. telephone service continued intermittently for awhile then stopped. . later, communication by runner.
V.A., SAN FERNANDO:	. HEAR System useless, transmission equipment made inaccessible under rubble from collapsed power supply building.
KAISER, PANORAMA CITY:	. outside telephone communication practically non-existent. No outgoing or incoming calls for several hours, or several days in some instances.

TABLE IV

DAMAGE TO BUILDING SERVICES	WATER/SEWAGE
OLIVE VIEW:	. no water supply. . no sewage. . piping broken. . boilers shifted up to 4 ft., and small fire created.
PACOIMA:	. water supply suspect, friend in Bishop brought in water in truck. . 3-5 hours to check out mains, bring boilers back on line. . no water in delivery area (obs) no way to clean up after delivery. . water squirts up from breaks in mains. . service curtailed by aftershocks. . leaks all over. . water knocked out.
HOLY CROSS:	. no water: supplied by local breweries. . sewage all right.
V.A., SAN FERNANDO:	. no information noted: not significant since buildings totally evacuated.
KAISER, PANORAMA CITY:	. city water cloudy and tasted different, but okay.

TABLE V

DAMAGE TO BUILDING SERVICES — GAS/MEDICAL GASSES

OLIVE VIEW:	. no information noted by staff interviewed: does not necessarily mean no failures.
PACOIMA:	. nearby gas line exploded. . lines severed, but leaks rapidly shut-off by plant engineering. . no oxygen, lines severed, but leaks rapidly repaired.
HOLY CROSS:	. service knocked out. . no oxygen or other medical gasses.
V.A., SAN FERNANDO:	. no information noted: not significant since buildings totally evacuated.
KAISER, PANORAMA CITY:	. leak in main gas line (4"). . March 20, fire.

TABLE VI