EXECUTIVE SUMMARY

The Robert M. Arnold Public Health Sciences Building was constructed on the campus of the Fred Hutchinson Cancer Research Center (FHCRC). The Public Health Sciences Building houses four Programs: Epidemiology, Cancer Biology, Biostatistics & Mathematics, and Cancer Prevention. Both laboratories and offices occupy Arnold Building. The building height is five stories (60') above grade. The structure also extends three stories below ground. There is an entrance plaza, service road, and turnaround at the building entrance. These public spaces are supported by a portion of the submerged structure.

This report is an investigation into the main lateral force resisting system of Robert M. Arnold Building on the Fred Hutchinson Cancer Research Center's campus in Seattle, Washington. The site of the building exposes it to high lateral loads of both wind and seismic nature. The report discusses methods of both computer modeling and manual calculation of the applied forces, their distribution through the building, and the effect this causes on the main lateral force resisting system. It was noted on the structural drawings that the owner wanted the building's structural design to be above the minimum standards dictated by the building code. The investigation found forces comparable to those listed on the structural drawings. The findings also noted that the drift ratio of the building was well below serviceability limitations of the American Society of Civil Engineers minimum design loads for buildings.

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BACKGROUND INFORMATION

The Robert M. Arnold Building was designed and completed prior to the City of Seattle's adoption of the International Building Code (IBC). The applicable building code, when the building was designed, was the 1997 Uniform Building Code (UBC) as amended by the Department of Planning and Development. The design of concrete structures shall also be in accordance with standards set forth by the American Concrete Institution (ACI). The Seattle Building Code is comprised of the 1997 Uniform Building Code and the amendments made by the City of Seattle. The current building code in Seattle is now the IBC. These design requirements will also be examined. Further investigations, analyses, and designs will comply with the current code. It is therefore necessary to look at any differences between the design requirements set forth by design professionals, the UBC and the IBC.

The Uniform Building Code refers to the American Institute of Steel Construction (AISC) for design provisions of steel structures. Regarding concrete construction, the UBC has based its own provisions on the American Concrete Institute 318 but has not explicitly adopted the standard. Certain portions of the Uniform Building Code reference specific sections of the American Society of Civil Engineers (ASCE) 7. One specific example of this is wind design. The section of ASCE 7 on wind design is referenced. However the UBC specifies its own method for determining wind pressures.

The International Building Code refers to AISC's design provisions for steel construction. The IBC has also adopted ACI 318 for the design of concrete structures. ASCE 7 is referenced regarding the minimum load for buildings.

GRAVITY LOADS

Dead Loads

As specified by the Seattle Building Code, the dead loads are considered to be, "the weight of all materials and fixed equipment incorporated into the structure". Unlike the live loads, there is no table specified in the code. Where necessary, minimum design dead loads from ASCE 7 will be used.

FLOOR DEAD LOADS

Description			
Superimposed			
Mechanical & Electrical Allowance		5	lb/ft^2
Partition Load		20	lb/ft^2
Floor Finishes		2.5	lb/ft^2
Ceiling Finishes		2.5	lb/ft^2
	Total	30	lb/ft^2
Non-Superimposed			
Concrete		150	lb/ft^3
	Total	150	lb/ft^3
Composite Concrete Deck		50	lb/ft^2
	Total	50	lb/ft^2

Table 3-1

Live Loads

Table 3-2 shows the live loads as obtained from the code and also those obtained from the structural drawings. Certain loads are not specified by the Seattle Building Code and do not fall into a broader category. The loads listed on the structural drawings in some areas differ from the code. For the purpose of analysis, the live loads determined by the design professionals will be used. The structural engineers had more information regarding building occupancy, building equipment, and building use. The office live load takes into account the additional loads of filing systems. In accordance with the Seattle Building Code, reduction of live loads is permitted. However, the structural engineers have specified that there will be no live load reduction for the first level through the fourth level.

Live Loads

Description	Uniform Load (lb/ft^2)		
	Uniform Building Code	Structural Drawings	International Building Code
Floor			
Offices	50	80	50
Levels 1—4 (Office)	50	75	50
Laboratories	-	100	60
Interstitial	-	25	-
Corridors	100	100	100
Parking	50	50	40
Sidewalks & Driveways	250	250	250
Roof			
Roof	25	25	20

Table 3-2

DESCRIPTION OF STRUCTURAL SYSTEM

Arnold Building is an interesting collage of structural systems. Different portions of this building employ different methods of supporting the necessary loads. The building itself consists of five stories above grade plus a mechanical “penthouse” on the roof, while also extending 3 stories below grade. The triangular transfer of load around the atrium provides an element of structural complexity unseen in rectilinear buildings. Arnold Building houses the Public Health Science Department of the Fred Hutchinson Cancer Research Center. FHCRC specified that the building be designed to a standard of structural integrity higher than that of the code.

Foundation

The foundation of the Public Health Sciences Building consists mainly of spread footings and wall footings. Where the foundation is required to resist lateral loads carried down by shear walls, the building uses deeper drilled piers. The average footing is about 12 square feet, however, sizes ranging from eight feet square to 28 feet by 24 feet. The depth ranges from 30 inches to 48 inches deep, but is typically around 40 inches deep.

Framing

The framing of Arnold Building is mainly composed of concrete structural elements; however, there are some portions of the building where steel has been used. Steel framing was used for the stairs and skylight in the atrium. A special stipulation was made by the structural engineers that the structure of the atrium be designed such that it would not cause any torsional load on the rest of the building. The columns on the fifth story are made of tube steel with typical size being TS 12x12x5/8. Steel was also employed in the design of the roof structure that houses the building’s mechanical equipment. The typical steel column in this area is a TS 4x4x4 ¼. The irregularity of the steel roof structure lends itself to atypical beam and girder sizes. They range from
W 10x12 to W 30x132. There also are a few steel columns in the main structure.

Almost all of the remaining portions of the structure are made of concrete. The columns are continuous cast in place reinforced concrete. The typical columns are 24 inches square and are on an average grid of 30 feet by 30 feet. The columns do not taper towards the top; however, the amount of reinforcement can vary. The shape of some columns varies. On certain floors, columns have a diameter of 24 inches instead of a width of 24 inches. Supporting Campus Drive, the turnaround, and the entrance plaza, under which the building extends, is an area of the building which uses cast in place reinforced concrete. The average beam is 24 inches wide by 30 inches deep.

Structural Slabs

The floor system of Arnold Building is mainly composed of two way post-tensioned concrete floor slabs. The slab in the basement is not post-tensioned but instead is made of fiber reinforced concrete. The portion of the building that is under the entrance plaza uses reinforced concrete slabs. The roof slab is composed of reinforced concrete. With the noted exceptions the typical floor system is a flat port-tensioned concrete slab with drop panels.

SEISMIC LOADING

Computer Modeling

The mass of building components plays a pivotal role when the site is subjected to seismic excitation. It is critical that these masses and their distribution throughout the building be determined accurately. In a structure as complex as the FHCRC's Public Health Sciences Building, manual calculation of mass properties becomes quite cumbersome.

A computer model in Bentley's RAM Structural System was generated for Arnold building. The model was used to determine the participating masses at each story. Some portions of structure that extend above the Upper Roof Level were lumped to the supporting roof level. These roof structures contain smaller braced frames that are discontinuous at the roof level. The roof level to which they were combined helps to distribute them to the main lateral force resisting system. If they were modeled as frame members in RAM they would not be supported by other frame members that would result in various errors and warnings in the program. The roof level below these members is assumed to act as a rigid diaphragm and to distribute the loads to the braced frames which are part of the main lateral force resisting system. The method for calculating the seismic load in RAM Structural System was the Equivalent Lateral Force Procedure per ASCE 7-02. While the atrium provides a large opening in the slabs of the main floor levels it is within the limit

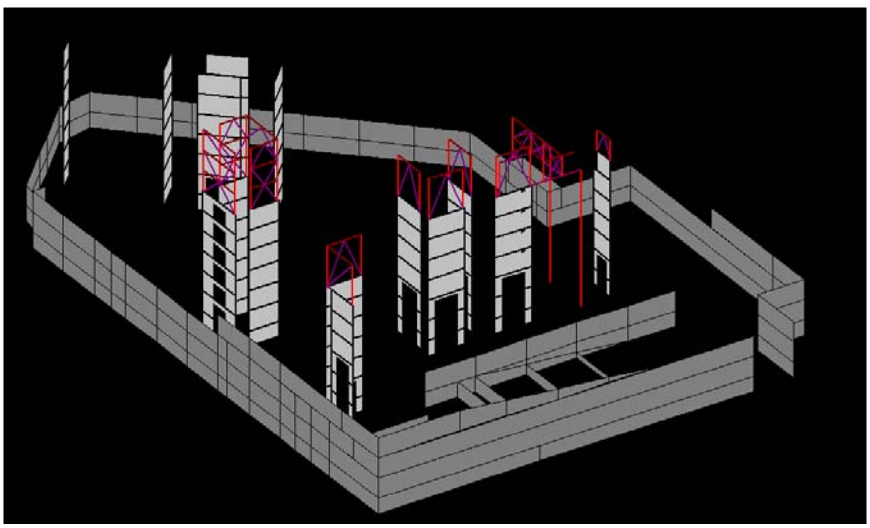

Figure 3-1

of 50% of the gross enclosed diaphragm area so that it does it does not constitute a Diaphragm Discontinuity Irregularity.

MANUAL VERIFICATION

Determination of Participating Mass

Manual methods of calculating weight and mass distribution were completed in order to verify the validity of the RAM model. The weights of the building components were first calculated. For steel members the linear weights as given in the AISC Steel Construction Manual were used. The linear nature of steel shapes simplifies locating the center of mass to locating the midpoint of the member. Steel construction constitutes only a small portion of the building, with the majority of Arnold Building being composed of concrete. The method for determining centers of mass for concrete elements was different. Having the structural plans drawn up in AutoCAD greatly simplified this task. The concrete structural elements of the building are mostly planar. Exploiting the planar geometry and Mass Properties command in AutoCAD concrete elements of the same depth and at the same elevation could be grouped together into regions; the area properties could be calculated. AutoCAD determines key properties such as area, location of the centroid, and moments of inertia. These areas could then be treated as plates. Using half of the story height for wall and column depths facilitates distributing the masses accurately by allowing half of the mass to be applied to the story below and half of the mass to be applied to the story above. Additional masses, such as exterior walls, elevator walls, and partition loads, were applied as either linear elements or area elements on the floor slab, similar to the application of mass dead loads in RAM and other computer modeling programs.

While determining the mass properties in AutoCAD of the various elements, the data was simultaneously entered into a Microsoft Access Database. The database allowed for the different elements of the building to be grouped according to story level. Querying the data allowed for the weighted coordinates of the center of mass for each story to be determined, as well as the weight of the story. Additionally, an approximate mass moment of inertia could be determined for each story under the thin plate assumption.

Determination of Rigidities

Following the determination of masses and their distribution, rigidities of the main lateral force resisting system were determined. A simplified method of determining braced frame rigidities was used that only considers the contributions of the diagonal braces. The stiffness of these elements was calculated through another query in the Microsoft Access Database previously mentioned. Subsequently, the center of rigidity was calculated through a method of weighted coordinates.

The main portion of the lateral force resisting system is composed of shear walls. The rigidity for each shear wall was calculated at each floor level by applying a unit force at the top of the wall. The lateral deflection of the wall was determined based on shear and bending deformation of the wall. For shear walls with openings in them, initially the solid wall rigidity was determined. Subsequently the wall was then broken down into strips of pier and beam elements. The individual rigidities and deflections for these elements were determined and then built up to determine the overall rigidity of the wall. Calculations of each wall rigidity were carried out using Microsoft Excel spreadsheets. The variations of the amount of segments in each wall did not lend itself to the use of the database. Centers of rigidity for each story was determined by using weighted coordinates similar to the method used for the braced frames, however, this was carried out in spreadsheets. A few samples of the shear wall spreadsheet are included in the appendices, a complete set for all shear walls is available upon request. Also in the appendices is a summary of the rigidities for each level of each shear wall.

Seismic story forces were calculated using the Equivalent Lateral Force Procedure in accordance with ASCE-7. These calculations were completed using a spreadsheet which can be seen below. Through manual calculations the seismic base shear was determined to be 5938 kips, which is close to the 5980 kips listed on the structural drawings.

Level	Manual	RAM
LVL PH	230.59	127.20
LVL RF	502.34	559.17
LVL ML	157.75	329.40
LVL 5	1612.01	1645.95
LVL 4	1086.70	1196.06
LVL 3	836.15	849.37
LVL 2	635.32	635.94
LVL 1	585.45	445.89
LVL D	291.86	131.49
BASE SHEAR	5938.16	5920.47

Table 3-3

Wind Loading

The design wind pressures for Robert M. Arnold building were determined in accordance with Method 2, the analytical method, of ASCE-7. This method was used in both the RAM Structural System, and manually. The manual calculation wind pressure was completed in Microsoft Excel. The pressures were then entered into the database aforementioned and forces were distributed to individual stories. The difference between the computer model and manual calculation of wind forces is due to limitations of software. The RAM model yields conservative results because Level 1 is only fully exposed on the east side of Arnold building due to changes in site grading. For examining the wind loads effects on the lateral system the loads determined in RAM will be used.

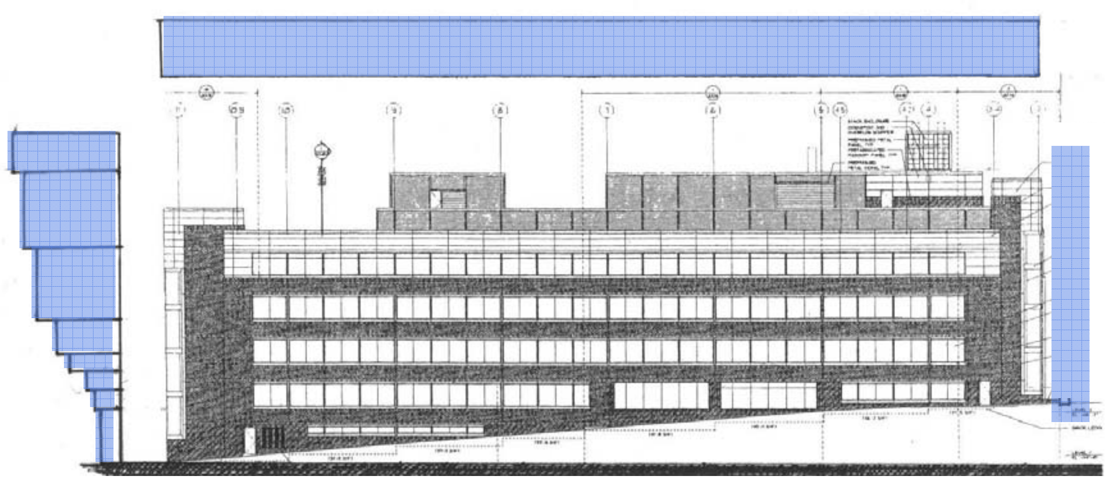

Figure 3-2

Distribution of Lateral Loads

The distribution of lateral story forces was based upon the relative rigidities of lateral force resisting elements. Both direct shear and torsional shear were distributed to the lateral members. Torsional shear was distributed based upon relative torsional rigidities. The appendices contain spreadsheets that calculate both the relative rigidities and the torsional rigidities/ torsional moment of inertia. In the appendices may be found the distribution of story shears to individual shear walls.

The lateral drift of Arnold Building was examined using the load cases generated in RAM structural system. The applied wind loads produced almost no drift at all. Seismic loads produced slightly higher story drifts but still were well within the 0.015 ratio provided by ASCE-7.

The shear walls of Robert M. Arnold Building typical call for 6000 psi concrete. In some locations it is noted on the shear wall elevations that an 8000 psi concrete mix is to be used for the lower stories. This is typically where the shear wall has an opening on the parking garage levels. All the shear walls have boundary elements and in some locations a special boundary element is required. These special boundary zones are discontinued at the slab of Level 3. Reinforcement in the special boundary zones is so extremely dense; mechanical couplers were required in order to reach full development without exceeding the maximum reinforcement ratio.

CONCLUSIONS

Using both a computer modeling program and hand calculations the seismic base shear of Arnold building was verified. Concerning lateral loads seismic loading seemed to be the controlling factor. The concrete construction of Arnold Building provides a significant amount of mass to participate in seismic events. The higher strength of the concrete in the shear combined, with the reinforcement of boundary elements and the use mechanical couplers together have significant implications on construction costs. The investigation into the lateral system of Arnold building shows that the lateral force resisting system is more than sufficient for the applied loads.