SENIOR THESIS, SPRING 2007

The Pennsylvania State University, Architectural Engineering Department

Structural Analysis of the Duquesne University Multipurpose/ Athletic Facility

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Structural Option
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Senior Thesis, Final Document
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DUQUESNE UNIVERSITY FORBES EXPANSION

FORBES AVENUE, PITTSBURGH, PA

PROJECT INFORMATION

Owner - Duquesne University
Architect - DRS Architects, Inc.
Structural - Atlantic Engineering Services
Mechanical - Dodson Engineering, Inc.
Electrical - Hornfeck Electrical
Construction - Jendoco Construction

Size - 125000 square feet
Height - 7 Stories
Project Cost - $24 million
Delivery Method - Design, Bid, Build

Construction Start - March, 2006
Anticipated Finish - January, 2008

MECHANICAL SYSTEM

- Six AHU's ranging from 5000 to 33000 cfm
- VAV system with terminal and fan power boxes
- Local reheat for individual space control
- 45 degree chilled water supplied by university chiller plant
- 110 psig steam supplied from university boiler plant, reduced to make 180 degree hot water

LIGHTING/ELECTRICAL SYSTEM

- 2000 Amp MSB provides 480/277V, 3 phase, 4 wire power
- Transformer converts 480/277V to 480V, 3 phase, 3 wire and 208/120V, 3 phase, 4 wire power
- Emergency 275KW Diesel Generator with AT switches
- Recessed 2'x2' or 2'x4' indirect fixtures in office areas
- Pendant mounted metal halide fixtures in gymnasiums

ARCHITECTURE

- Style is consistent with the existing campus buildings
- Exterior materials include a red brick and glass facade, with intermediate strips of rock faced CMU
- Steel pedestrian bridge arches above Forbes Avenue, connecting the facility an adjacent parking structure

STRUCTURAL SYSTEM

- Beams, girders, and columns are wide flange steel memebers
- Composite slab and metal deck on composite steel framing
- Braced frames used to resist lateral forces
- Foundation consists of auger cast piles and grade beams

MICHAEL J. SZOTT - STRUCTURAL
HTTP://WWW.ARCHE.PSU.EDU/THESIS/EPORTFOLIO/2007/PORTFOLIOS/MJS577/

Executive Summary

Currently under construction in Pittsburgh, PA, the Duquesne University Multipurpose Facility will be a dominating feature of the Forbes Avenue Corridor. The University's newest facility is a 125,000 square foot activity center housing everything from academic to athletic spaces.

The building's lateral resisting system is a configuration of concentrically braced frames located around the perimeter of the structure. For my first investigation, I chose to study whether or not there was a more efficient bracing configuration than the existing tension only scheme. I assessed three alternate designs including concentric frames evaluated for tension and compression, chevron bracing, and alternating diagonals or "K" bracing. Each system was judged on the basis of structural performance, drift control, and overall weight. My second investigation was focused on the gravity system of the structure. As stated above, many of the floors are shared by spaces housing both athletic and sedentary spaces. Since the inactive areas will require a certain level of privacy, floor vibrations from the surrounding active areas should be limited. Using the rhythmic vibration criteria noted in chapter 5 of AISC Design Guide 11, I evaluated and designed several critical areas of this building.

To further investigate spatial relationships, several noise significant wall and floor/ceiling assemblies were studied. These systems were evaluated based on STC and IIC acoustical rating criteria.

In the constant pursuit of a more efficient design, cost is always a consideration. For both the gravity and lateral areas of my depth study, a detailed cost comparison was performed. Material, fabrication, and labor costs were included in each estimate as well as manufacturing location and delivery complications.

I have concluded the following based on the above noted study:

- The alternate chevron bracing scheme results in the lightest weight and most inexpensive lateral system for these particular locations.
- The alternating diagonal scheme is the most expensive lateral system due to the increased size of bracing and frame members.
- Overall building drift was controlled best by the chevron and concentric tension-compression lateral systems.
- When analyzing vibration criteria for the long spanning bays, castellated beams meet the rhythmic criteria outlined in Design Guide 11, and offer a significant weight savings when compared to traditional wide flange shapes.
- Open web steel joists were considered, but found to be inefficient when considered for the long spanning floor areas.

Multipurpose Athletic Center

Project Background

Duquesne University, located in the city of Pittsburgh, is in the process of expanding its campus. The land being developed is situated along Forbes Avenue, adjacent to the A.J. Palumbo Center, and "will be used for commercial and educational purposes, improving both the entrance to campus and the Forbes Avenue corridor." The first phase of the project, a multipurpose athletic facility, is currently under construction, and should be ready for use in January 2008. The building itself will be home to a variety of spaces including retail outlets, fitness and recreation facilities, athletic offices, and a ballroom/conference center.

Duquesne University Multipurpose Center
Project Fact Sheet

Owner:	Duquesne University
Architect:	DRS Architects
Construction:	Jendoco Construction
Structural:	Atlantic Engineering Services
HVAC:	Dodson Engineering
Electrical:	Hornfeck Electrical
Building Size:	125000 square feet
Building Height:	7 stories
Project Cost:	$24 million
Delivery Method:	Design, Bid, Build
Construction Start:	March, 2006
Anticipated Finish:	January, 2008

The lower floors of the structure will house a Barnes and Noble bookstore as well as other retail outlets (Starbuck's coffee, etc…). The subsequent floors will house facilities for use by Duquesne University faculty and students. The second and third floors will house some classroom and office space intermixed with aerobic and dance studios. The third floor will also be home to the first of two gymnasium spaces. Lastly, the fourth and fifth floors will be used predominantly for a gymnasium (fourth) and a ballroom/banquet space (fifth).

During the process of researching this structure in previous Technical Assignments, several opportunities emerged for my spring thesis studies, as follows:

- Vibration control
- Material optimization
- Lateral stability/Torsion
- Lateral system design
- Design efficiency

Site Location

When driving to and from the city of Pittsburgh, the “Forbes Avenue corridor” serves as a barrier between Duquesne University campus and the city itself. As shown in the above mapping, the new athletic facility is being built on the outskirts of Duquesne’s campus. This building is the first in a long line of projects that will further enhance the college campus.

As construction draws to a close on this project, more construction in the same area will be beginning. The Pittsburgh Penguins have recently finished a deal guaranteeing their stay in Pittsburgh for the next 30 years. The site of the new arena will be a block away, and clearly visible from the upper ballroom area of the Duquesne facility. Along with the new arena, the city skyline will also provide a spectacular view from the ballroom balconies and pre-function areas.

Under Construction 8/2006

Current Construction 4/2006

General Architecture

Pittsburgh Pennsylvania, with over 1900 bridges in its surrounding area, is known as the "City of Bridges". The predominant exterior feature of the Multipurpose Facility branches out from the building in the form of a steel pedestrian bridge, connecting to an adjacent parking garage. The bridge itself provides a lively extension, sprawling over top of the Forbes Avenue landscape.

The architectural layout of the Multipurpose Facility is typically rectangular. Each floor is primarily a rectangular grid system divided into publicly and privately functioning areas. The building will be an extension of the campus, providing auxiliary spaces for students and faculty to further exercise their minds and bodies. While the building is owned by the university, the building will serve the community as well. A lower level coffee shop and bookstore will be located on the ground floor, and be the primary entrance for the public. For students, the primary entrance will be from campus connected pedestrian bridge.

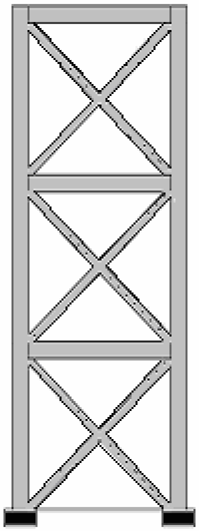
The exterior of the building is clad in red brick, masonry units and glass panels. The lower two stories are clad in an off white color masonry, broken with a strip of rough faced CMU. The brick façade is generally uninterrupted. It is, however, separated from itself at the fifth floor by another strip of rough faced CMU. This relatively plain façade is complimented on every face with areas of expansive glazing. These large window sections allow the occupants of the building to experience the outdoor environment while working, or working out inside. Other than the extended bridge, no structural elements are exposed to public view.

Structural Depth Study

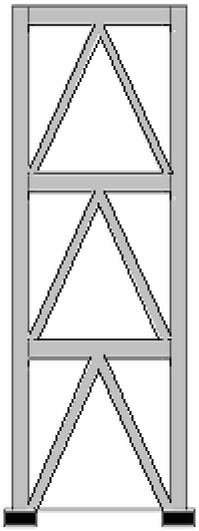
During my work in analyzing this structure, I have come to the conclusion that the best way to further engineer this construction is to attempt optimization. Revisiting the lateral system design and performing a vibration analysis on the gravity system will establish my new performance criteria for a structurally sound and efficient design.

Lateral System Redesign

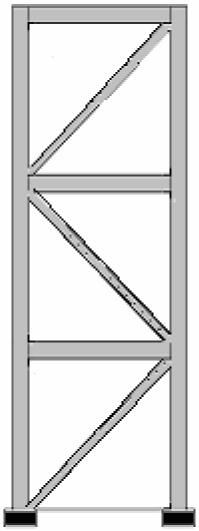
My first analysis will center on the redesign of the existing lateral system. Currently, lateral resistance is provided by a system of concentrically braced steel frames located on all four faces of the structure. The braces are designed as HSS members acting to resist forces in tension only. For the redesign, I will continue to use steel frames, and evaluate the three different bracing configurations shown below.



X-Bracing
(Tension and Compression)



Chevron Bracing

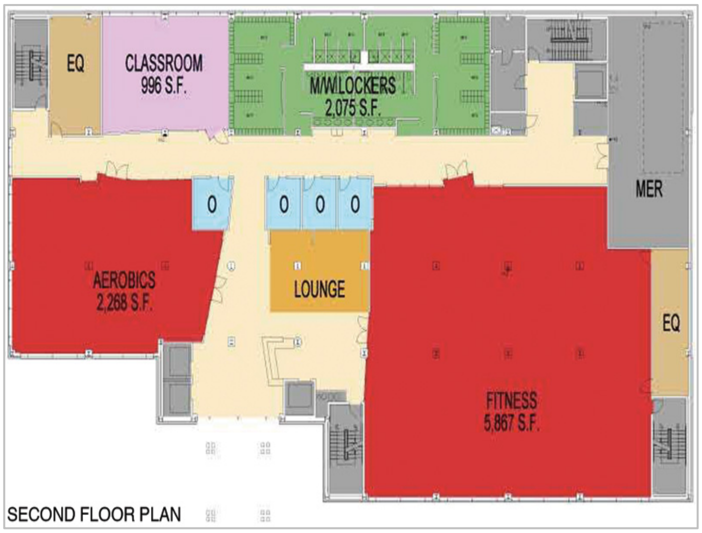


“K”-Bracing

In performing a lateral analysis during Technical Assignment 3, the frames were checked based on the assumption that the diagonal braces were designed to take the full lateral force in tension. If the frames were designed under this assumption, then it is possible that the diagonal braces are not being used to their full potential. If this is true, then a redesign of the lateral system could result in lighter, more efficient structure.

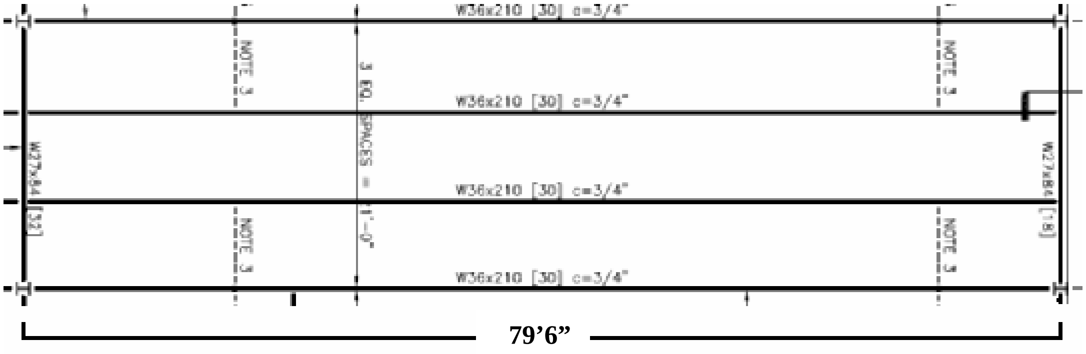
Previous research from Technical Assignment 3 yielded high torsional forces acting on the upper stories of the structure. After verifying my calculations, I will investigate possible solutions to reducing these torsion forces. Also, analysis results from RAM Frame software will be further scrutinized as a further confirmation of my calculations.

Gravity System Analysis



My second analysis will focus on the gravity framing system. As constructed, the floor framing is composite steel wide flange beams and girders. Throughout the building, different floor areas are used for a variety of activities. Some areas that are used for aerobic or athletic activities are near (above/below/next to) office, classroom, or retail spaces. I will analyze these athletic spaces based on acceptable vibration criteria and make changes accordingly.

Along with intermixed activities, the fourth floor gymnasium and fifth floor ballroom are framed with long spanning members, and may be more susceptible to unacceptable vibration conditions. These conditions will be analyzed just as the other spaces listed above.

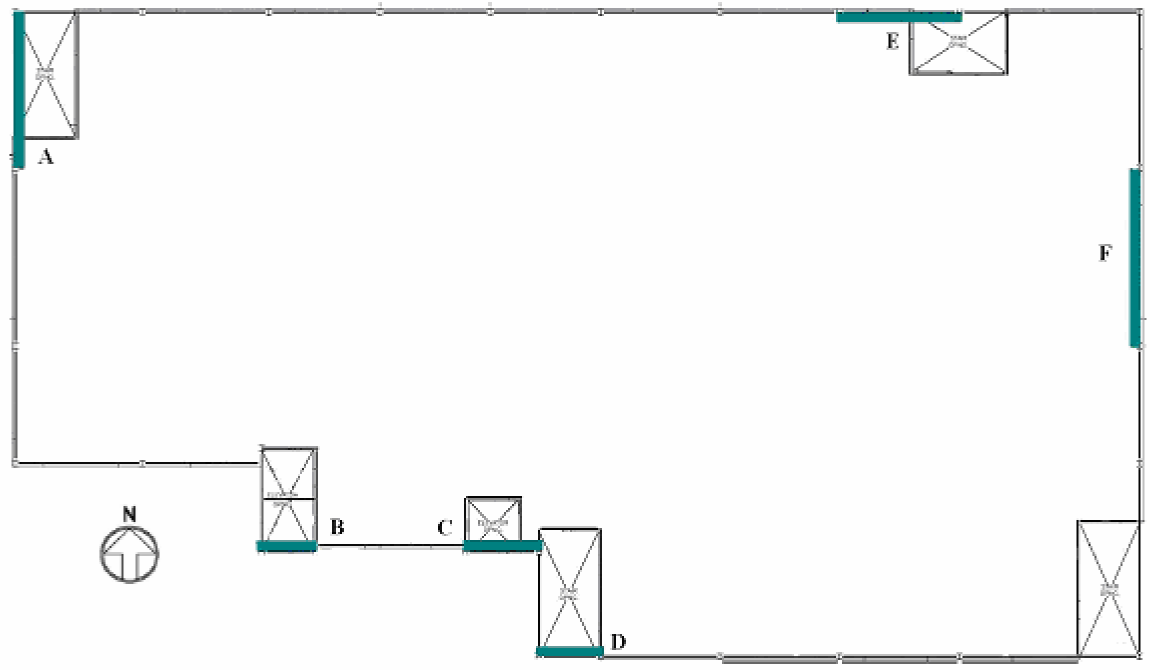


Within all of the previous research topics is the subject of optimizing each component of the structural system. Therefore, the overall goal of my research will be to create a more cost effective and structurally efficient building, without reducing the quality or efficiency of the other building systems.

Existing Lateral System

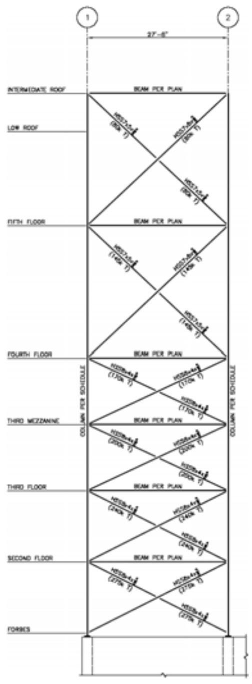
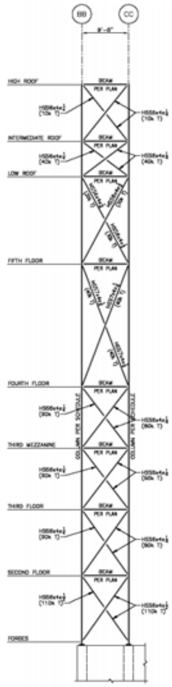
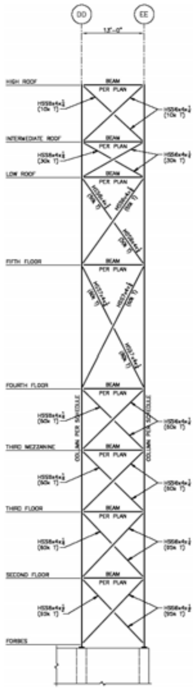
The Duquesne University Multipurpose Facility uses concentrically braced steel frames to resist lateral loads. Each lateral element or frame is located along the perimeter of the structure (as shown below). The upper level interior spaces, gymnasiums and ballroom, are not as favorable for lateral elements because they require so much open space. Exterior locations such as stair wells and elevator cores lend themselves as unobstructed positions for the braced frames. These areas are devoid of windows and other openings allowing the frames to be well hidden from view. Where other frames are needed, exterior elevations without windows or openings were again chosen to hide these elements.

On the South face of the building, frames are constructed around both elevator shafts and a stair tower. The same is true on the North and West faces of the building where bracing is positioned at stair towers. The typical columns used in each of bracing elements are W14's ranging from W14x53 to W14x132. Each floor to floor section makes use of a series of concentrically braced HSS members ranging in size from HSS6x4's to HSS8x4's, 1/4" to 5/8" thick. Each bracing member is designed to see 30 – 275 kips in tension only.



Letters correspond to the elevations on the following page

Existing Braced Frame Elevations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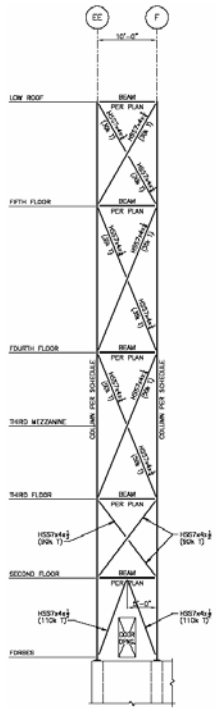
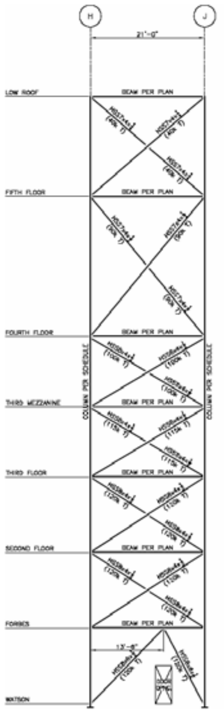
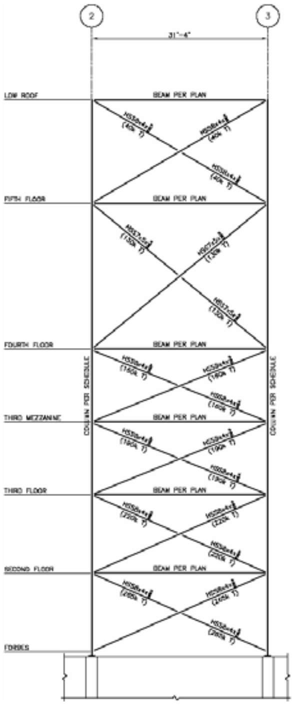
		
D	**E**	**F**

Design Criteria

Building Code:	International Building Code, IBC 2003 Referencing ASCE 7-02
Structural Concrete:	Code Requirements for Structural Concrete, ACI 318 Specifications for Structural Concrete, ACI 301
Structural Steel:	Manual of Steel Construction AISC, 13th Edition LRFD/ASD

Applicable Loadings: Gravity Loads

Live Loads (ASCE 7-02, Table 4.1)

Lobbies and Public Spaces	100 PSF
Corridors (above first floor)	80 PSF
Mechanical	75 PSF (assumed)
Athletic Floors	100 PSF
Stairs and Exits	40 PSF
Offices	50 PSF

Dead Loads

Partition Allowance	20 PSF
Reinforced Concrete Slab	150 PCF
Curtain Wall System	15 PSF
MEP	5 PSF
Metal Decking	2-3 PSF
Joist/Beam Weight	Specific to each member

Snow Loading (ASCE Section 7, Figure 7.1)

Ground Snow	30 PSF
Flat Roof Snow	21 PSF

All other factors = 1.0

$p_f = 0.7C_eC_tIp_g = 0.7(1.0)(1.0)(1.0)(30\text{psf}) = 21$ PSF

Applicable Loadings: Lateral Loads

Seismic Loads (ASCE7-02)

Seismic Design Category	A
Seismic Use Group	II
Importance Factor (I_E)	1.25
S_S	0.128
S_1	0.057
S_{DS}	0.102
S_{D1}	0.065
Site Class	C
Response Coefficient	
N-S	0.0231
E-W	0.0231
Response Modification Factor	
N-S	5
E-W	5

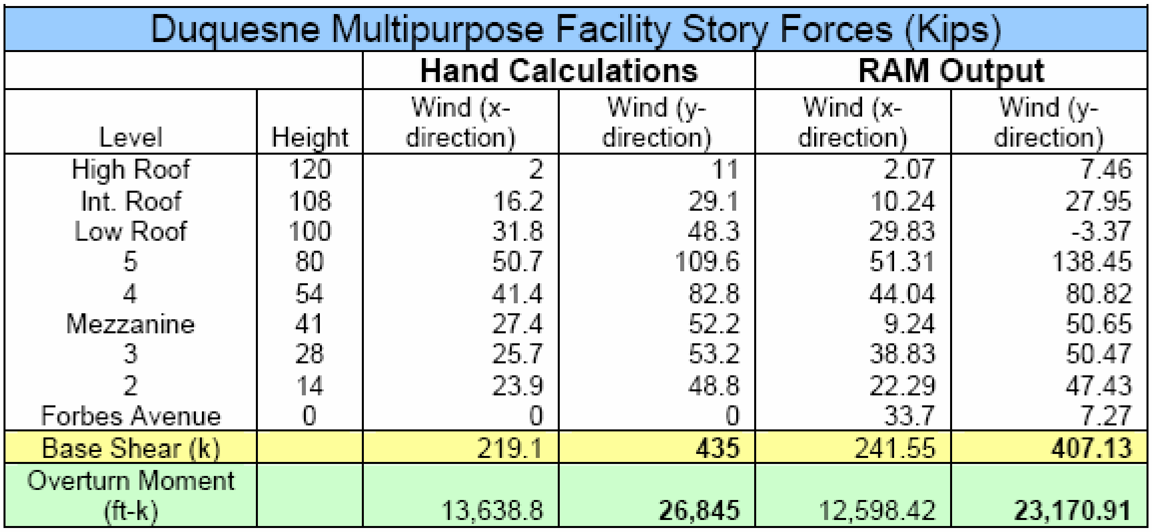
While seismic forces were calculated during the initial lateral analysis of the building, they will not control the lateral design. Under IBC2003 section 1616.6, it states that an analysis must be performed except when structures are assigned to Seismic Design Category A, which includes this structure. However, when the seismic classifications of the building were entered into RAM, the result was that the seismic forces typically did not control the design of the members. The lateral forces from the wind caused the highest stresses in the lateral system. In the end, the controlling design factor for the lateral system was mostly drift of the structure, not stress.

Wind Loading (ASCE 7-02)

Basic Wind Speed	90 MPH
Exposure Category	III
Enclosure Classification	Enclosed
Building Category	B
Importance Factor	1.15
Internal Pressure Coefficient	0.18

Base Shear (N/S): 435 kips
Overturning Moment: 26845 ft-kips

Base Shear (E/W): 219.1 kips
Overturning Moment: 13640 ft-kips



Duquesne Multipurpose Facility Story Forces (Kips)					
		Hand Calculations		RAM Output	
Level	Height	Wind (x-direction)	Wind (y-direction)	Wind (x-direction)	Wind (y-direction)
High Roof	120	2	11	2.07	7.46
Int. Roof	108	16.2	29.1	10.24	27.95
Low Roof	100	31.8	48.3	29.83	-3.37
5	80	50.7	109.6	51.31	138.45
4	54	41.4	82.8	44.04	80.82
Mezzanine	41	27.4	52.2	9.24	50.65
3	28	25.7	53.2	38.83	50.47
2	14	23.9	48.8	22.29	47.43
Forbes Avenue	0	0	0	33.7	7.27
Base Shear (k)		219.1	**435**	241.55	**407.13**
Overturn Moment (ft-k)		13,638.8	**26,845**	12,598.42	**23,170.91**

The lateral loads imposed on the building are distributed into story forces and then further distributed to each frame on the basis of relative stiffness. Because there seems to be no practical way to reposition the existing frames, the existing locations will be used in the redesign. Leaving the frames in place also will allow for a more direct comparison between the different bracing configurations.

Analysis Methods

Because the original frames were designed using allowable stress design, I will use ASD combinations to check the new frames. Using allowable stress analysis will allow for a more direct comparison between the existing frames and the alternates. The following combinations were checked:

- D + L
- D + (W or 0.7E)
- D + 0.75L + 0.75S
- **D + 0.75L + 0.75W **Controls****
- 0.6D + W

After finding the controlling load combinations, RAM Advanse was used to analyze and design each individual frame. RAM's "Optimize Model" command was used to determine the new member sizes in the alternate bracing configurations. The optimize/code check commands choose the appropriate members based on multiple analytical iterations, selecting a member with adequate strength and minimal weight.

Upon completing the individual frame design, each alternate system was checked using RAM Structural System's Frame module.

Torsion Revisited

During previous study, the question of excessive torsional forces arose. Hand calculations suggested that the excessive forces were confined to the upper 3 stories of the building. During the analysis, the relative stiffness of the each full frame was considered. In doing so, the extra, one story, frames for the intermediate and low roofs were omitted. The omissions of these frames are a possible reason that the torsional forces at the upper stories were calculated to be so large.

When recalculating the torsional forces associated with the upper stories of the structure, including the stand alone frames (for the intermediate and low roof levels) dramatically reduced the previously calculated forces. These new forces will be included with the existing shear in the redesign of each lateral frame. Because the torsion forces have turned out to be relatively small when compared to the wind forces imposed on the structure, I expect them to have only a small impact on the overall design of the alternate systems.

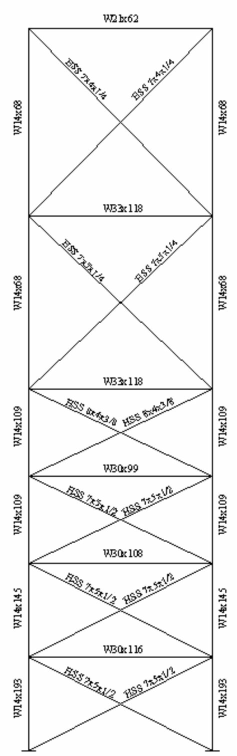
Lateral Alternates

Information contained in the following pages includes:

- Frame Elevations
    - Alternate #1: Modified Concentric Frames
    - Alternate #2: Chevron Bracing
    - Alternate #3: K – Bracing

- Lateral Analysis Results (found on page 17)
    - Alternate frame weight comparison
    - Alternate frame drift comparison
    - Conclusions

Alternate #1: Modified Concentric Frames



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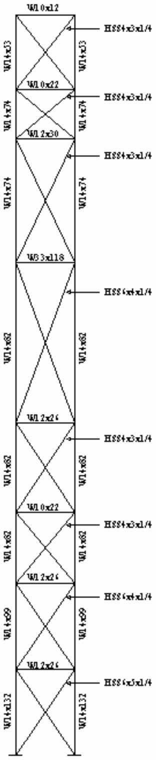

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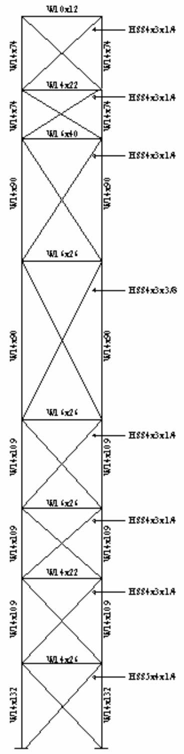

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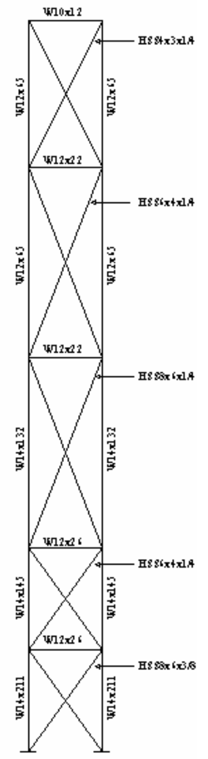

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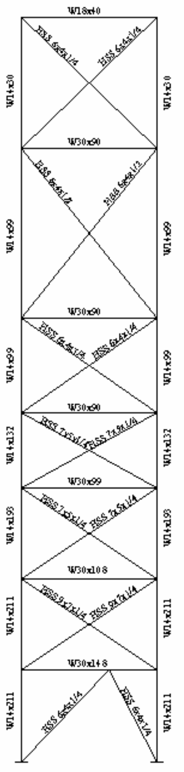

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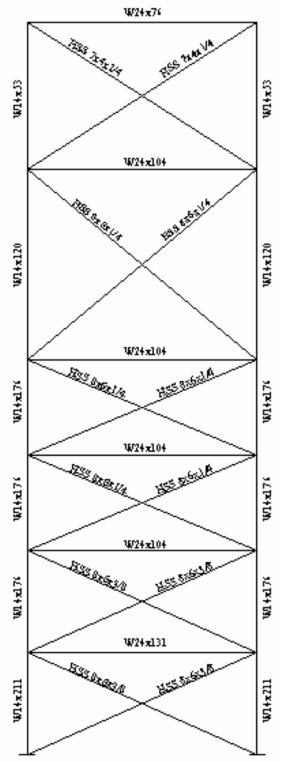

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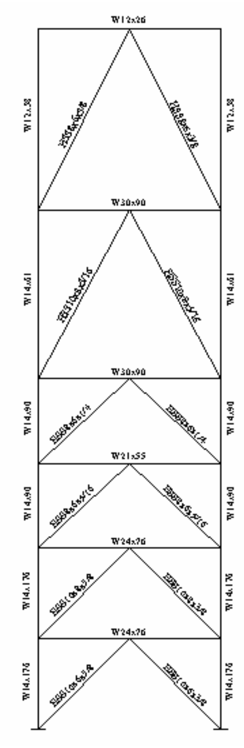
Alternate #2: Chevron Bracing



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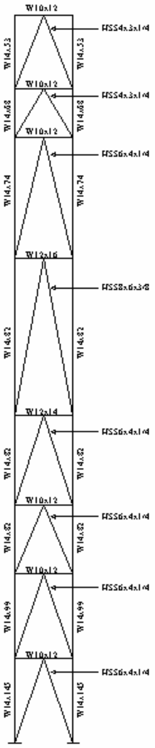

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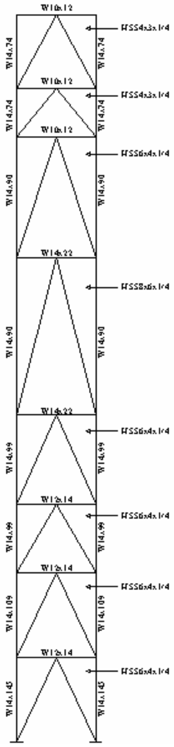

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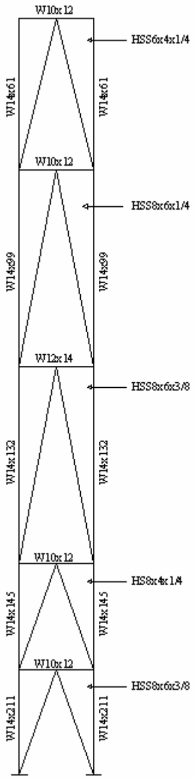

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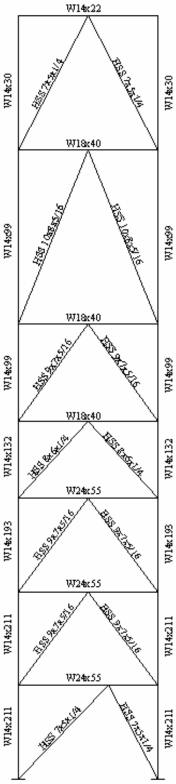

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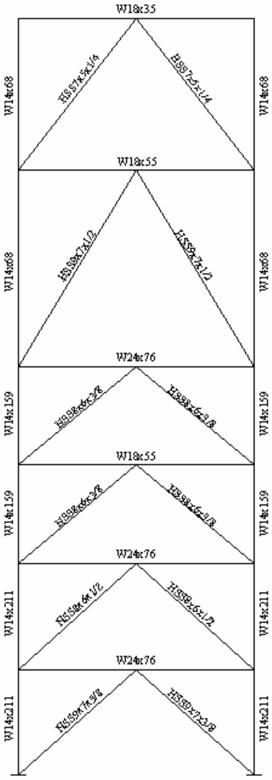

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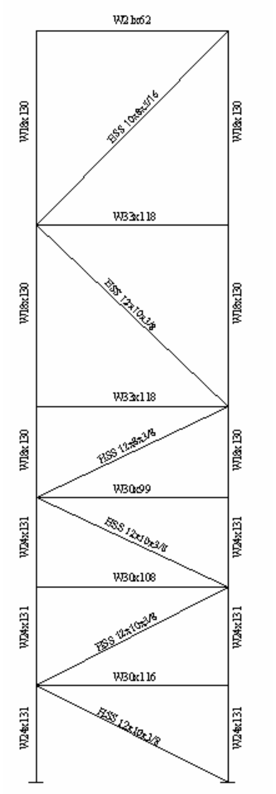
Alternate #3: K-Bracing



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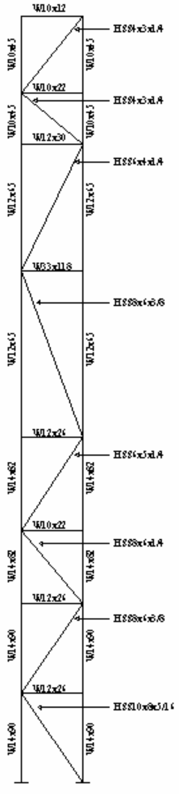

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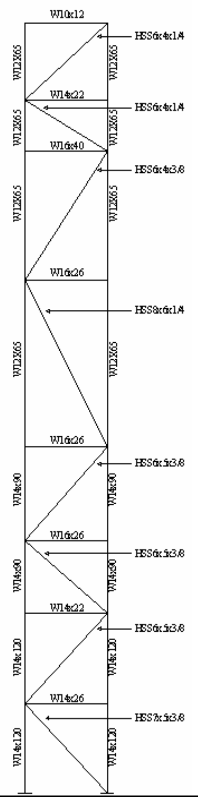

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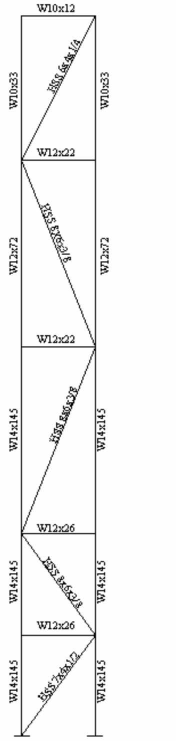

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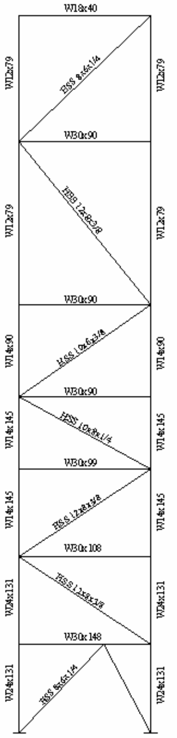

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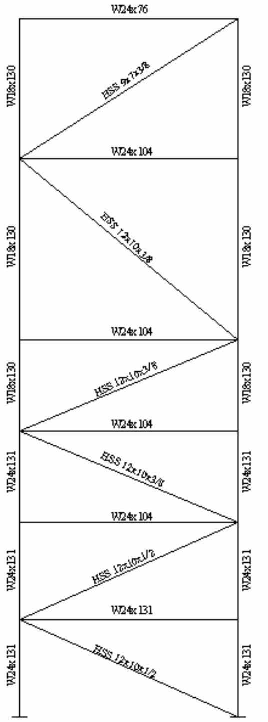

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Lateral Analysis Results

Lateral System Weight Comparison (kips)			
	Component weights		
Bracing Layout	**HSS Braces**	**W shapes**	**Totals**
X-Bracing (T only)	46.5	198.7	245.2
X-Bracing (T-C)	38.4	202.5	240.9
Chevron Bracing	37.9	178.2	216.1
K-Bracing	37.4	192.4	229.8

Overall Building Drift (in.)				
Bracing Layout	**Drift @ HR**	**Drift @ IR**	**Drift @ 5th**	**H/400**
X-Bracing (T only)	5.6	3.3	2.1	3.96
X-Bracing (T/C)	4.6	2.6	1.5	3.96
Chevron Bracing	4.8	2.7	1.5	3.96
K-Bracing	5	2.9	1.6	3.96

The results of my analysis indicate that the chevron bracing scheme is clearly the lightest of the four systems studied. While the HSS bracing members are of a similar weight in each alternate system, the wide flange beams in the chevron configuration are able to be dramatically reduced. This reduction is possible because each set of braces halves the span of each beam. Each beam supports the masonry façade, and thus its design is controlled by masonry deflection limits (L/600 or 0.3”) and not shear or flexural stress. Initially, I had concerns that the beam sizes would increase due to added shear stresses caused by the chevrons distributing their forces into each frame. In this case however, the beams are oversized leaving most members at approximately 30% of their shear capacity.

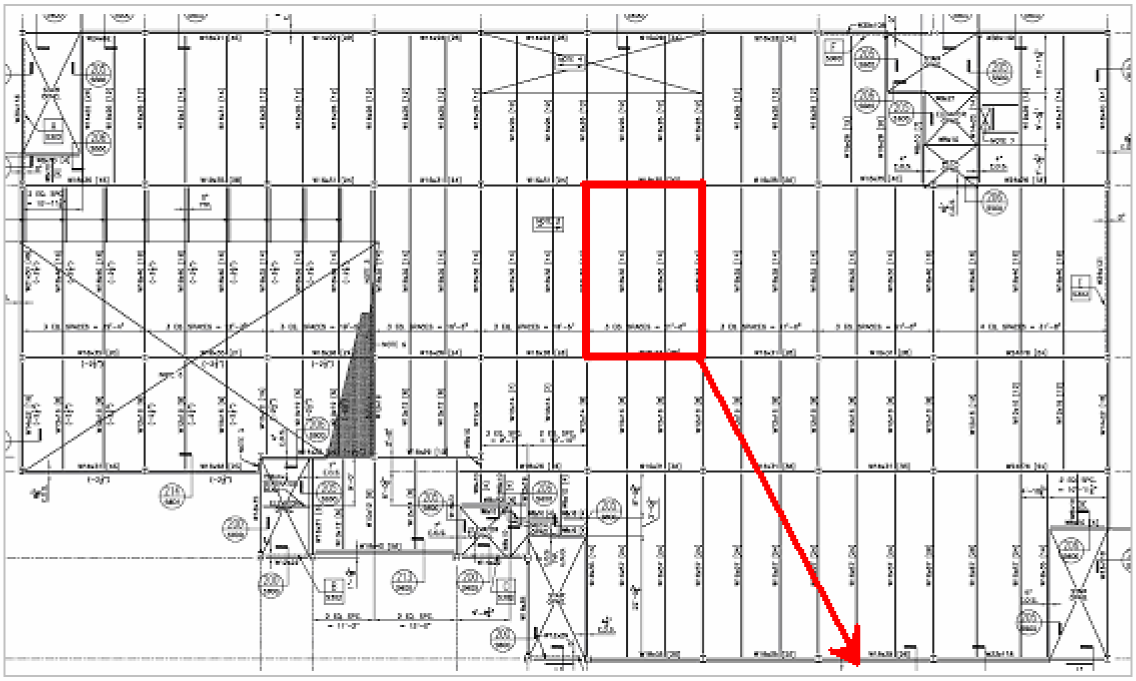
One concern that arose in conjunction with all four designs was that of overall building drift. A bridge structure connects this facility to an adjacent parking structure at the 5th floor/ballroom level. The original construction documents call for the two structures to be kept separate by a minimum 1” expansion joint. At the 5th floor level, the minimum deflection (of the four systems) was found to be 1.5”, as can be seen above. Although it would be unfavorable if the building was to push or lean against the bridge, one would assume that an extra 1/2” of drift would not be cause for great concern. In addition, the building drift is calculated for a worst case wind loading scenario and would not likely happen often enough to cause damage or undo stresses in the bridge structure.

Another drift question arises at the HR level. At this height, the practical drift limit of H/400 is exceeded by 0.6”-1.6”. This seems to be of no consequence due to the following:

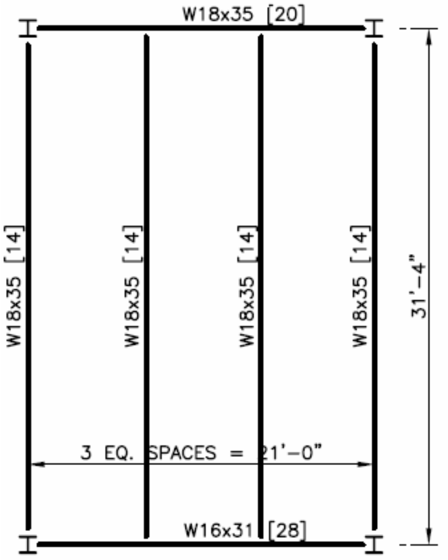
- H/400 is an accepted practical standard and not part of any structural code
- The HR level is part of an “atrium” space, and unoccupied

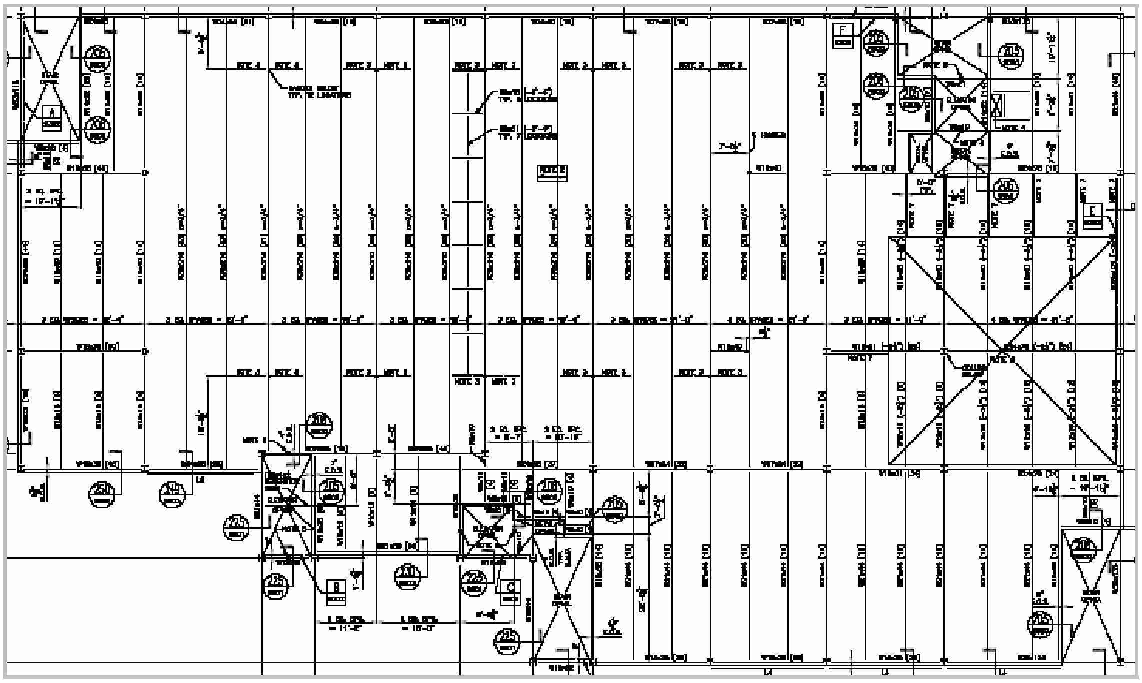
Existing Gravity System

Duquesne University's Multipurpose Athletic Facility is supported by a steel superstructure, including a composite steel floor system. Each of the first three floors is framed in rectangular bays, ranging in size from 20'x20' to 21'x34'. The lower floors are used to house a multitude of mixed facilities including a bookstore and coffees shop, offices, classrooms, aerobic/dance rooms, and athletic spaces.



**** Typical Framing Plan----floors Forbes-3rd ****





Gymnasium and Ballroom Framing Plans

Of the two athletic/gymnasium spaces, one is framed similarly to that of a typical floor, while the other is designed under different circumstances. The second gymnasium is located on the 4th floor, directly above gymnasium one. The 5th floor is used to house a ballroom or entertainment space. Since these spaces must be completely devoid of columns, the framing consists of W36x210's with ¾" camber, spanning 80'. These beams frame into smaller span girders, typically W27x84 members.

Analyzed Spaces

As stated in the introductory portion of my structural depth section, I will focus my analysis on floor vibration. This analysis seems to be an especially relevant issue due to the close proximity of active and inactive spaces at the lower levels as well as the ballroom space that will be used for both dancing and dining purposes. Within the new Duquesne University Multipurpose Facility, vibrations caused by rhythmic activity are the most prevalent. In an attempt to look at the most critical areas, I will study 4 separate areas in which rhythmic excitation will be the most severe, including:

- 2nd floor aerobics studio
- 3rd floor gymnasium (typical bays)
- 4th floor gymnasium (long spans)
- 5th floor ballroom (long spans)

Vibration Design Criteria

For my analysis, I will consult AISC's Design Guide 11 (DG 11), Floor Vibrations Due to Human Activity. As stated in the design guide, "the primary objective is to provide basic principles and simple analytical tools to evaluate steel framed floor systems for vibration serviceability due to human activity."

Floor Vibrations in General

When designing a floor structure, strength and general serviceability requirements (deflection, etc…) are always taken into consideration. Other serviceability issues, such as vibration requirements, are not always given proper consideration, especially if it is not requested by an owner, or demanded by the use of sensitive equipment. Often times, vibration checks are not completed until some sort of issue with the structures performance is reported.

A person's perception of "annoying floor vibrations" is strongly related to their environment and state of activity. For example, a person working in an office or classroom will not tolerate mildly perceptible vibrations, while a person undertaking physical activity will generally tolerate "vibrations 10 times greater." An inactive person located near an area of rhythmic activity will generally tolerate some level in between.

Rhythmic Excitation

Rhythmic excitation of floor systems is addressed in Chapter 5 of DG 11. The criterion for design is based on activity occurring over either a partial or entire floor area. It is used to evaluate "structural systems supporting aerobics, dancing, or audience participation events." The method of evaluation is based on two significant system characteristics: floor frequency and acceleration. The following equations (from DG 11) were used to determine the natural frequency of the floor system and its peak acceleration, respectively.

$$f_n = 0.18\sqrt{g/(\Delta_j + \Delta_g + \Delta_c)}$$

$$f_n \geq (f_n)_{req'd} = f\sqrt{1 + \frac{k}{a_o/g}\,\frac{\alpha_i w_p}{w_t}}$$

$$\frac{a_p}{g} = \frac{1.3\alpha_i w_p / w_t}{\sqrt{\left[\left(\frac{f_n}{f}\right)^2 - 1\right]^2 + \left[\frac{2\beta f_n}{f}\right]^2}}$$

For rhythmic design, the following tables offer acceptable values for use in conjunction with the previous design equations.

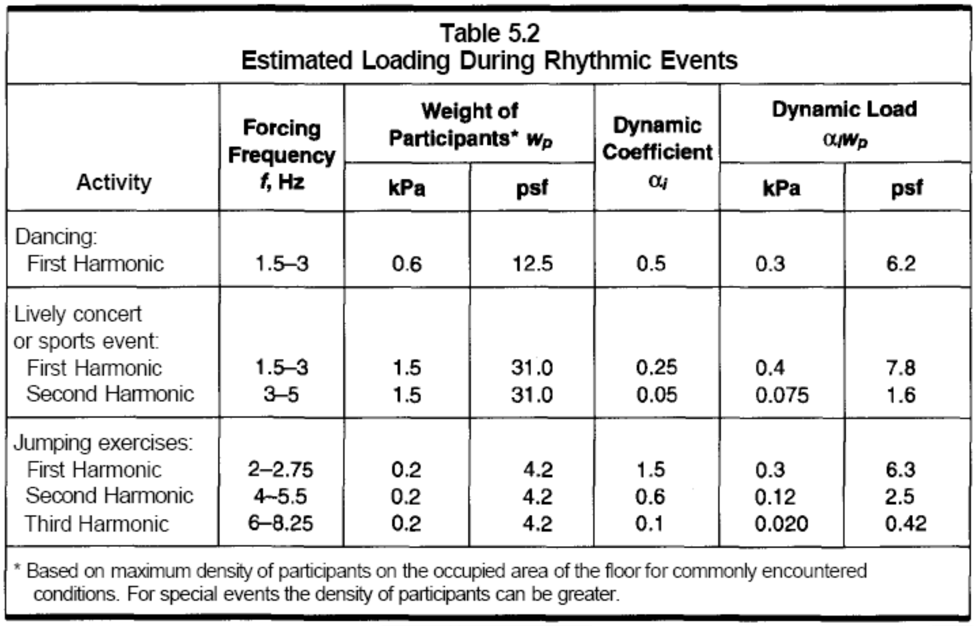


Table 5.2
Estimated Loading During Rhythmic Events

Activity	Forcing Frequency f, Hz	Weight of Participants* w_p		Dynamic Coefficient α_i	Dynamic Load $\alpha_i w_p$	
		kPa	psf		kPa	psf
Dancing: First Harmonic	1.5–3	0.6	12.5	0.5	0.3	6.2
Lively concert or sports event: First Harmonic	1.5–3	1.5	31.0	0.25	0.4	7.8
Second Harmonic	3–5	1.5	31.0	0.05	0.075	1.6
Jumping exercises: First Harmonic	2–2.75	0.2	4.2	1.5	0.3	6.3
Second Harmonic	4–5.5	0.2	4.2	0.6	0.12	2.5
Third Harmonic	6–8.25	0.2	4.2	0.1	0.020	0.42

* Based on maximum density of participants on the occupied area of the floor for commonly encountered conditions. For special events the density of participants can be greater.

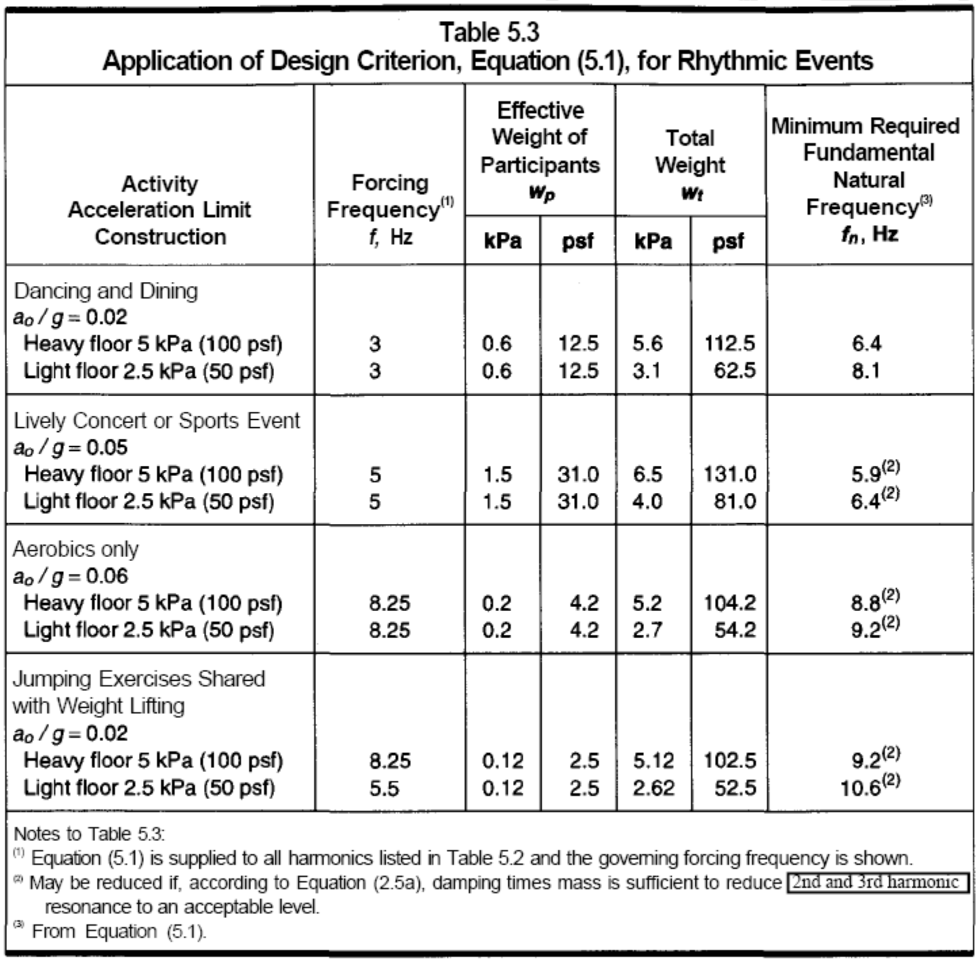


Table 5.3
Application of Design Criterion, Equation (5.1), for Rhythmic Events

Activity Acceleration Limit Construction	Forcing Frequency(1) f, Hz	Effective Weight of Participants w_p		Total Weight w_t		Minimum Required Fundamental Natural Frequency(3) f_n, Hz
		kPa	psf	kPa	psf	
Dancing and Dining $a_o / g = 0.02$ Heavy floor 5 kPa (100 psf)	3	0.6	12.5	5.6	112.5	6.4
Light floor 2.5 kPa (50 psf)	3	0.6	12.5	3.1	62.5	8.1
Lively Concert or Sports Event $a_o / g = 0.05$ Heavy floor 5 kPa (100 psf)	5	1.5	31.0	6.5	131.0	5.9(2)
Light floor 2.5 kPa (50 psf)	5	1.5	31.0	4.0	81.0	6.4(2)
Aerobics only $a_o / g = 0.06$ Heavy floor 5 kPa (100 psf)	8.25	0.2	4.2	5.2	104.2	8.8(2)
Light floor 2.5 kPa (50 psf)	8.25	0.2	4.2	2.7	54.2	9.2(2)
Jumping Exercises Shared with Weight Lifting $a_o / g = 0.02$ Heavy floor 5 kPa (100 psf)	8.25	0.12	2.5	5.12	102.5	9.2(2)
Light floor 2.5 kPa (50 psf)	5.5	0.12	2.5	2.62	52.5	10.6(2)

Notes to Table 5.3:
(1) Equation (5.1) is supplied to all harmonics listed in Table 5.2 and the governing forcing frequency is shown.
(2) May be reduced if, according to Equation (2.5a), damping times mass is sufficient to reduce 2nd and 3rd harmonic resonance to an acceptable level.
(3) From Equation (5.1).

Gravity System Evaluation

Before performing any type of analysis, there seemed to be two alternate types of framing members that would satisfy both vibration and economic concerns; open web steel joists and castellated beams. Both types of framing were considered based on presumed weight savings and the ability to span long distances.

During my evaluation, it I found it difficult to meet specific vibration criteria in both the typical and long span situations using steel joists. Depth of the floor system became an issue when the joist sizes needed to increase by 12-18” in order to meet a total load deflection requirement of L/360. Also, the use of joist would require a closer spacing, resulting in at least 2-3 times more joists than existing wide flange framing.

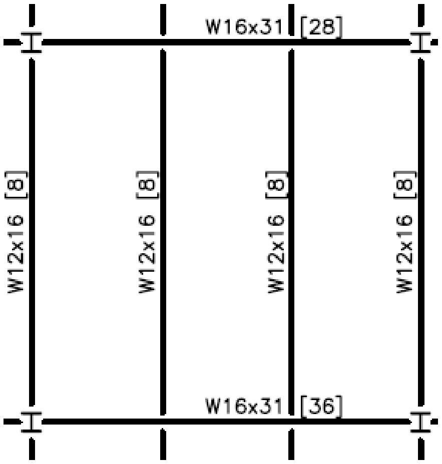
2nd Floor Aerobic/Fitness Studios

Existing Framing: (20’8” span)

Beams: **Composite W12x16 @ 7’o.c.**
Girders: **Composite W16x31 (21’0”)**
Slab: **(NWC) 4.5” slab, 2” deck**
Other: **10 psf wood overlay**
DL + w_p: **89 psf**

	$f_{n(reqd)}$ (Hz)			
$f_{n(act)}$	1st Harmonic	2nd Harmonic	a_p/g (%g)	a_o/g (%g)
8.48	5.38	8.03	0.045	0.06

Based on the information calculated above, this particular floor area is acceptable for vibration based on aerobic only use. The natural frequency of the floor system exceeds both the first and second harmonics and the acceleration limit is satisfactory. Since the natural frequency of the floor is closest to the forcing frequency for the 3rd harmonic, the peak acceleration was checked for that particular case.



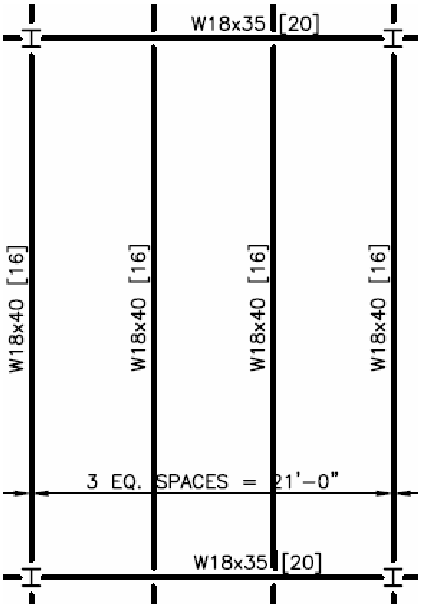
Existing Framing: (31’4” span)

Beams: **Composite W18x40 @ 7’o.c.**
Girders: **Composite W18x35 (21’0”)**
Slab: **(NWC) 4.5” slab, 2” deck**
Other: **10 psf wood overlay**
DL + w_p: **89 psf**

	$f_{n(reqd)}$ (Hz)			
$f_{n(act)}$	1st Harmonic	2nd Harmonic	a_p/g (%g)	a_o/g (%g)
5.18	5.38	8.03	0.45	0.07

Even with a larger beam for the longer span, the natural frequency of the floor system does not meet the required 1st or 2nd harmonic frequencies for aerobic loading conditions.

With a retail space below, the vibration concerns in this aerobic space should be properly rectified. First, I attempted to use a W18 member to reach the required criteria. Once the beam weight became double the original, I decided to switch to a deeper member. In trying to minimize any kind of depth increase, the largest beam chosen was a W21. After much trial and error, the beam settled on to meet the vibration requirement was a W21x83.

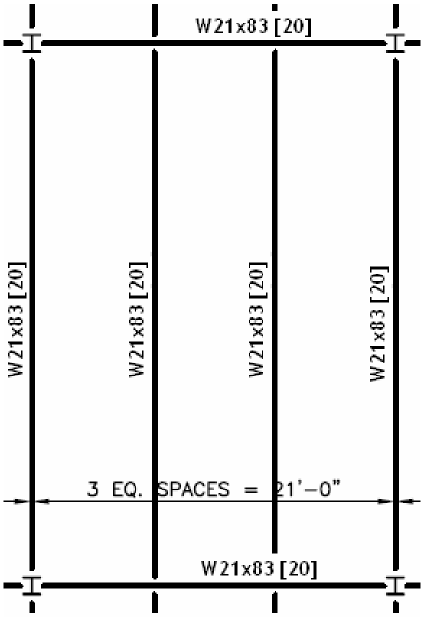


New Framing: (31’4” span)

Beams: **Composite W21x83 @ 7’o.c.**
Girders: **Composite W21x83 (21’0”)**
Slab: **(NWC) 4.5” slab, 2” deck**
Other: **10 psf wood overlay**
DL + w_p: **89 psf**

	$f_{n(reqd)}$ (Hz)			
$f_{n(act)}$	1st Harmonic	2nd Harmonic	a_p/g (%g)	a_o/g (%g)
8.07	5.38	8.03	0.051	0.06

With the increase in beam and girder size, deflections (which are inversely proportional to floor frequency) decreased, and the first two harmonic frequencies were met. Furthermore, the peak acceleration was also limited, making the floor acceptable for the aerobic vibration criteria. If W21 beams were deemed to be too large, one could use lower forcing frequencies to lessen the required frequencies, and obtain acceptable results.



3rd Floor Gymnasium (typical bays)

Existing Framing: (31’4”span)

Beams: **Composite W18x35 @ 7’o.c.**
Girders: **Composite W16x31 (21’0”)**
Slab: **(NWC) 4.5” slab, 2” deck**
DL + w_p: **89 psf**

At this gymnasium level, the floor is framed in the typical style used in the lower levels of the Duquesne University facility. It is framed with similar members and at the same span and spacing of the second aerobic bay. When analyzing the joist mode only, the framing is more than satisfactory, performing at a peak acceleration of around 5%**g**.

	$f_{n(reqd)}$ (Hz)			
$f_{n(act)}$	1st Harmonic	2nd Harmonic	a_p/g (%g)	a_o/g (%g)
8.43	4.97	7.6	0.047	0.07

When analyzing the combined joist and girder modules, the results are as follows:

	$f_{n(reqd)}$ (Hz)			
$f_{n(act)}$	1st Harmonic	2nd Harmonic	a_p/g (%g)	a_o/g (%g)
5.78	4.97	7.6	0.111	0.07

While the peak acceleration limit is exceeded, the gym is not a total failure. Assuming the participants using the gymnasium would not be disturbed by their own induced vibrations, the acceleration limits could be increased slightly to around 10-15%**g**. Unfortunately the gym is not isolated. Office space below and an adjacent weight lifting facility dictate that the vibrations caused by the gymnasium should be held to a reasonable criterion of 5%**g**. To meet more strict criteria, I would recommend changing the framing to W 21x83 beams and girders as was done for the aerobic spaces. In addition, increasing the slab depth to 7.5” would bring the required harmonic frequencies under the existing natural floor frequency.

4th Floor Gymnasium (long spans)

Existing Framing: (79’6” span)

Beams: **Composite W36x210 @ 7’o.c.**
Girders: **Composite W27x84 (21’0”)**
Slab: **(NWC) 4.5” slab, 2” deck**
DL + w_p: **89 psf**

	$f_{n(reqd)}$ (Hz)			
$f_{n(act)}$	1st Harmonic	2nd Harmonic	a_p/g (%g)	a_o/g (%g)
3.89	4.27	6.8	0.089	0.10

The second gymnasium space is quite different than the first. This is the first level that is framed in a long spanning condition. Also, this floor is one that is used solely for athletic purpose, relaxing the condition of designing for sensitive areas on that particular floor. With that said, I will use a peak acceleration criterion for the gym of 10%**g**.

The existing floor system does not meet the frequency requirements, but its peak acceleration is below the new limit. While the floor seems to be marginally acceptable, possible improvements could be made by using an alternative system. First, non-composite open web steel joists were considered, but were not able to practically meet vibration requirements over such a great span. One system that met strength, weight and vibration requirements was castellated beams. A castellated beam is a wide flange section that is cut along its web in a flat saw tooth pattern, shifted, and welded back together to create a deeper beam. The new beam contains hexagonal web openings, and is stiffer than the original. The resulting member is one that is lighter and can be used to span greater lengths.

Castellated beams used in the adjacent Duquesne University Parking Garage

Castellated Beam Framing:

Beams: **Composite CB50x169 @ 7'o.c.**
Girders: **Composite W27x84 (21'0")**
Slab: **(NWC) 4.5" slab, 3" deck**
DL + w_p: **89 psf**

	$f_{n(reqd)}$ (Hz)			
$f_{n(act)}$	1st Harmonic	2nd Harmonic	a_p/g (%g)	a_o/g (%g)
4.6	4.27	6.8	0.051	0.10

The use of castellated beams provides a lighter overall floor system, meeting the 1st harmonic frequency requirement and reducing the peak acceleration of the floor. Even when computed using the 2nd harmonic forcing frequency (5.5 Hz) the peak acceleration is close to the prescribed 0.10 limit.

a_p/g (%g)	a_o/g (%g)
0.116	0.10

5th Floor Ballroom (long spans)

Existing Framing: (79’6” span)

Beams: **Composite W36x210 @ 7’o.c.**
Girders: **Composite W27x84 (21’0”)**
Slab: **(NWC) 4.5” slab, 2” deck**
DL + w_p: **89 psf**

$f_{n(act)}$	$f_{n(reqd)}$	a_p/g (%g)	a_o/g (%g)
3.89	5.4	0.105	0.02

In my first attempt to analyze this ballroom space, I have considered more than half of the floor area to be used for dancing. This may be a somewhat unrealistic assumption, but it will be used to asses the current state of the framing. The results above indicate that the floor is not only designed below the required natural frequency but also has an extremely high peak acceleration value when compared to the allowable maximum for ballroom spaces. This information suggests that occupants dining on the same floor will experience a high level discomfort due to excessive vibrations.

For my second evaluation, I made the decision to consider only a portion of the floor area be used for dancing. This assumption was made after reviewing an AISC engineering journal paper written by Dr. Linda Hanagan entitled “Dynamic Amplitude Prediction for Ballroom Floors”. The paper discusses “a modification in the design of long span ballroom floors, where dancing activities are likely to take place in only a limited area of the bay”. This approach is used to modify the constant “k”, and in turn reduce the calculated peak acceleration of the floor system. The equations used to determine the modified k factor are shown below.

$$k = \frac{2\pi}{\ell_g \ell_j}\left(\sqrt{c_j}+\sqrt{c_g}\right)\left[\ell_j\sqrt{c_j}\left(\ell_{g2}-\ell_{g1}\right)\left(\cos\frac{\pi\ell_{j1}}{\ell_j}-\cos\frac{\pi\ell_{j2}}{\ell_j}\right) + \ell_g\sqrt{c_g}\left(\ell_{j2}-\ell_{j1}\right)\left(\cos\frac{\pi\ell_{g1}}{\ell_g}-\cos\frac{\pi\ell_{g2}}{\ell_g}\right)\right]$$

*Ch. 2 of DG11 defines “k” to be 1.3 for dancing

$$c_j = \frac{\Delta_j^2}{\pi^2\Delta_j^2+16\Delta_j\Delta_g+\pi^2\Delta_g^2}$$

$$c_g = \frac{\Delta_g^2}{\pi^2\Delta_j^2+16\Delta_j\Delta_g+\pi^2\Delta_g^2}$$

In my first attempt to use this new criterion, I chose to load half the span of each bay. In doing so, the modified constant k=0.92. The new framing and resulting values are as follows:

Beams: **Composite W40x372 @ 7’o.c.**
Girders: **Composite W30x90 (21’0”)**
Slab: **(NWC) 4.5” slab, 2” deck**

$f_{n(act)}$	$f_{n(reqd)}$	a_p/g (%g)	a_o/g (%g)
5	5.4	0.03	0.02

Using the modified factor improved both the frequency and peak acceleration numbers greatly, but not to an acceptable level. After careful consideration, I chose to reduce the area used for dancing to ¼ of the 80' span. Once again the k factor was reduced (k=0.46), and the peak acceleration reached an acceptable level.

a_p/g (%g)	a_o/g (%g)
0.019	0.02

This increased design is sufficient for vibration criteria, but is extremely heavy compared to the existing framing. Once again, castellated beams were chosen as a lighter alternative to the existing wide flange shapes.

Castellated Beam Framing:

Beams:	**Composite CB50x221 @ 7'o.c.**
Girders:	**Composite W27x84 (21'0")**
Slab:	**(NWC) 4.5" slab, 2" deck**
DL + w_p:	**89 psf**

$f_{n(act)}$	$f_{n(reqd)}$	a_p/g (%g)	a_o/g (%g)
5.4	5.4	0.019	0.02

The castellated beam system meets vibration requirements and is approximately the same weight as the existing floor system. For those two reasons, the castellated members are the most efficient choice to be used for this design.

Gravity Analysis Results

	Framing Weight (kips)	
Floor Use (Floor #)	Existing	Alternate
Ballroom (5th)	428.9	406.2
Gym (4th)	377.5	321.9
Gym (3rd)	127.4	162.8
Aerobic (2nd)	132.2	153.8
Totals	1066	1044.7

Using the vibration criteria for steel framed floor systems outlined in AISC Design Guide 11, I was able to design each floor system in a satisfactory manner. During the process of analyzing the typically framed aerobic and gym areas, it became evident that the most practical solution to vibration related issues was to increase beam depth. Even when considering spatial requirements for floor to ceiling height, the 3" depth increase is not enough to cause concern.

In dealing with the long spans, castellated beams were determined to be the most effective floor system based on weight and serviceability. The use of these members at the 4th floor gym level reduced the beam weight from 210 PLF to 169 PLF. The ballroom area was designed in a slightly different manner due to the more strict vibration criteria. This criterion did not allow the weight of this area of the floor system to be reduced; however, the use of castellated beams kept the weight approximately the same as the existing system. The ability to use castellated beams in another long spanning area lessened the overall weight of the entire floor.

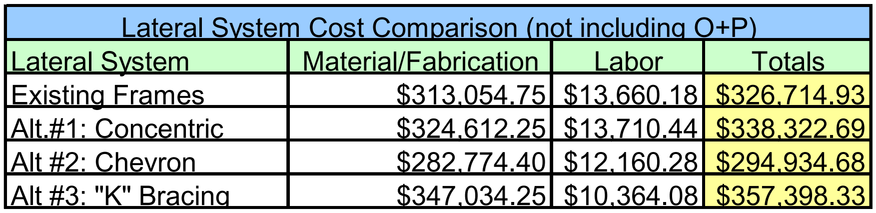
Although the use a castellated beam system was a benefit in terms of weight savings, the depth of each beam was increased by 14". The clear height for each gymnasium was cut from 23'0" to 21'8". Each gym's primary use is for basketball, a sport that requires a certain amount of unobstructed overhead space. While a 21'8" ceiling would be unusable for competitive high school or college athletics, it is perfectly acceptable for recreational play.

Breadth Study: Economy of Construction

To make a valid comparison between both alternate lateral and gravity systems, and to determine if they are indeed feasible alternatives, a cost analysis was necessary. In order to perform this analysis, I calculated material, fabrication, erection, and delivery costs for both the existing and alternate systems.

Lateral System

After designing each alternate lateral system, I used RAM Frame to perform a detailed take-off of all included material. I then used R.S. Means Construction Cost data to determine material and labor of each alternate. The following dollar values include shop fabrication and delivery costs.



Lateral System Cost Comparison (not including O+P)

Lateral System	Material/Fabrication	Labor	Totals
Existing Frames	$313,054.75	$13,660.18	$326,714.93
Alt.#1: Concentric	$324,612.25	$13,710.44	$338,322.69
Alt #2: Chevron	$282,774.40	$12,160.28	$294,934.68
Alt #3: "K" Bracing	$347,034.25	$10,364.08	$357,398.33

As shown above, the chevron system is, overall, the most inexpensive system. This is largely due to the reduced size of the lateral frame beams, and the lack of extremely large bracing members. The most expensive system is the “K” bracing scheme, due in part to diagonal braces that are twice as large as those used in any of the previous designs. When considering that the price per pound of HSS members is higher than their wide flange counterparts, this increase in cost is justified.

When looking only at labor costs, “K” bracing is the most inexpensive system by almost $2000 dollars. This design offers the least amount of bracing to column connections as well as the least amount of bracing members to set into place. The erection schedule associated with this, and all of the alternatives (according to R.S. Means daily output figures), is approximately 4-6 days.

Gravity System

Improving the vibration characteristics of a floor system generally translates into an increase in cost. With that said, in certain cases different structural framing configurations or members can be used to ensure a consistent or even diminishing dollar value. For the Duquesne University Multipurpose Facility, the upper stories provided an opportunity to increase vibrational quality while maintaining a reasonable price tag.

Existing Gravity Framing per Floor (not including O+P)			
Floor No.	Material/Fabrication	Labor	Totals
2	$148,817.05	$10,943.67	$159,760.72
3	$143,289.60	$11,070.40	$154,360.00
4	$453,475.10	$10,612.77	$464,087.87
5	$452,528.50	$9,665.95	$462,194.45
			$1,240,403.04

Alternate Gravity Framing per Floor (not including O+P)			
Floor No.	Material/Fabrication	Labor	Totals
2	$173,202.95	$11,216.79	$184,419.74
3	$183,722.60	$11,112.59	$194,835.19
4	$357,415.10	$28,596.20	$386,011.30
5	$458,540.10	$36,454.99	$494,995.09
			$1,260,261.32

The above cost analysis (completed using R.S. Means 2007) shows that the redesign of the gravity system, for the four floors analyzed, is a feasible undertaking. First, the 2nd and 3rd floor levels saw a sizeable increase in material costs due to larger framing members in the designated fitness and aerobic areas. This increase in cost, however, is offset by the configuration, and intended use of the 4th and 5th floor.

At the 4th floor gymnasium level, a less strict vibration criterion was imposed due to the type of activity associated with that floor. Since total beam depth was not a critical issue, a lighter, stiffer, and deeper castellated beam member was used. The decrease in total weight resulted in an $80000 cost savings for this floor.

The 5th floor ballroom level demanded more strict vibration criterion than any of the previous areas. Again, castellated beams were used to address the long span condition without dramatically increasing the weight, and overall cost of the floor. As can be seen in the figures above, the raw material costs associated with the alternate framing were almost identical to that of the existing system. However, the labor costs related to castellated beams increase more than three times that of regular wide flange sections.

One factor affecting the overall cost of the alternate systems 4th and 5th floors are delivery charges for the castellated sections. In speaking with CMC Steel Products, a fabricator of castellated beams, I learned that the nearest location that 80’ members could be manufactured is Hope, Arkansas. Due to the length of the members, the highway driving restrictions associated with such a shipment, and the distance traveled, material delivery is a prime contributor to increased cost.

Breadth Study: Acoustic Performance

Acoustical performance of floor and wall assemblies is considered in most every building design. In this particular case, the intermixing of facilities lends itself to having several different activities going on at each floor level. Offices, aerobic rooms, weight lifting areas, gymnasiums, classrooms, and other spaces are all located in close proximity to each other. This proximity can lead to unwanted noises and disturbances at inopportune times. Improving upon the existing acoustic qualities throughout the structure will benefit everyone inside.

More specifically I will focus on the acoustical properties at five different areas; two floor assemblies and three wall assemblies. Because the floors are all the same (4.5" concrete on 2" metal deck), I will look at the most critical and least critical areas. They are:

- 2nd floor aerobic/office (wall)
- 2nd floor MEP/fitness (wall)
- 4th floor gymnasium/studio (wall)
- Watson bookstore/Forbes bookstore (floor)
- 3rd floor gym/2nd floor classroom (floor)

Rating Criteria

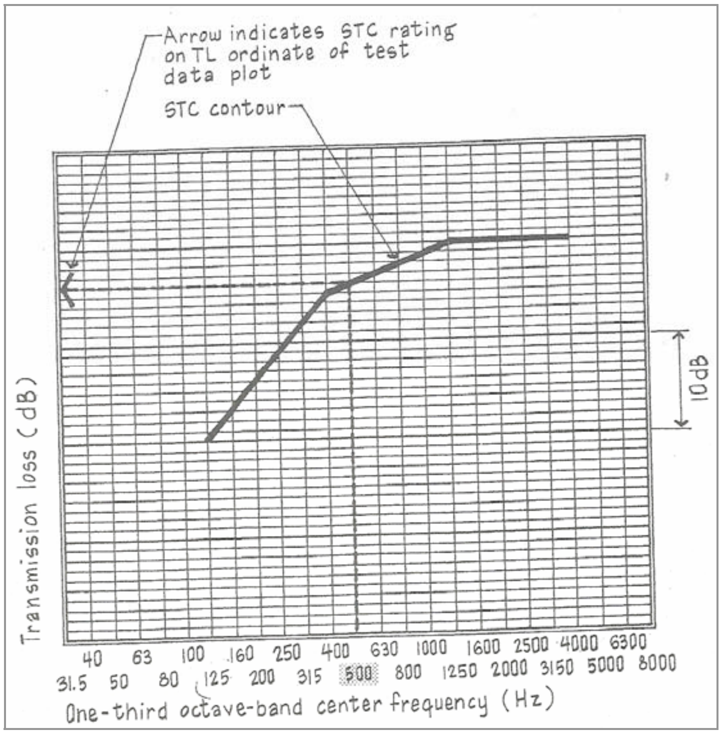
In analyzing the appropriateness of each separating assembly, I will be using STC and IIC rating criteria.

STC Rating Criteria

STC, or sound transmission class, is a single number rating of the airborne sound transmission loss (TL) performance of a construction measured at standard one-third octave band frequencies (Egan 201). A higher number STC rating is indicative of a barrier that is efficient at blocking sound transmitted within the given range of frequencies.

The STC rating contour, as shown on the next page, is used to determine STC ratings based on an ASTM procedure. The contour is shifted to fit the TL data of a particular construction, consistent with the following criteria:

- The maximum deviation of the test curve below the contour at any single test frequency shall not exceed 8 dB
- The sum of the deviations below the contour at all frequencies of the test curve shall not exceed 32 dB (on average, 2 dB per frequency)



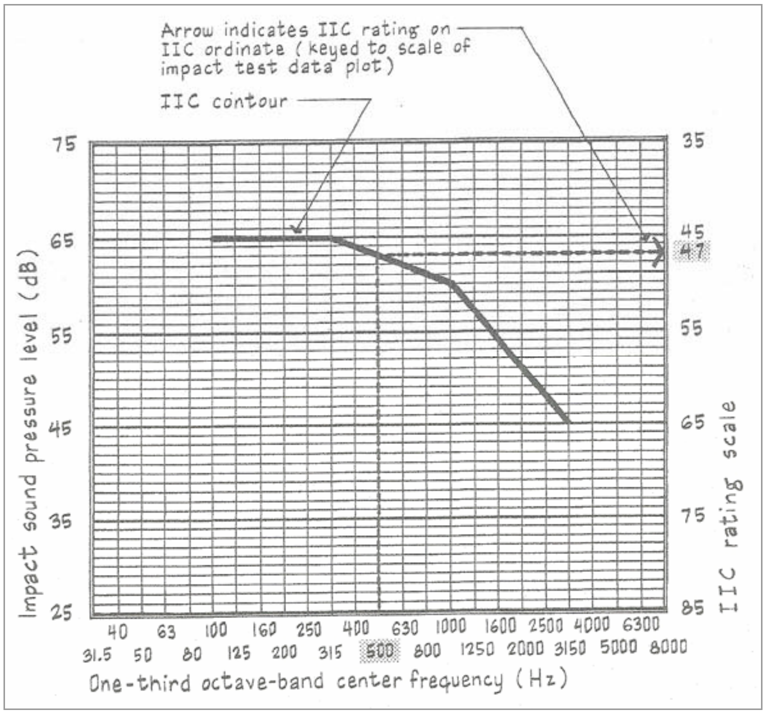
After fitting the STC contour to the TL data for the give wall system, the STC rating number is read as the TL number corresponding to the 500 Hz coordinate. For the purposes of my acoustical analysis, I will be using the TL data and STC ratings from the Egan text, as well as cross referencing (or if the construction is not available, using) the *Catalog of STC and IIC Ratings for Wall and Floor/Ceiling Assemblies*, issued by the California Department of Health Services.

IIC Rating Criteria

IIC, or impact isolation class, is a single number rating of the impact sound transmission loss performance of a floor-ceiling construction measured at standard one third octave band frequencies (Egan 250). As with the STC rating, the higher IIC rating is indicative of a barrier that is efficient at blocking impact sound transmitted within the given range of frequencies. The rating method is based on sound pressure levels produced in a room directly below the test floor.

The IIC rating contour, as shown on the next page, is used to determine IIC ratings based on an ASTM procedure. Obtaining an IIC rating from the chart is done in a similar fashion to the STC rating by using the following limitations:

- The maximum deviation of the test curve above the contour at any single test frequency shall not exceed 8 dB
- The sum of the deviations above the contour at all frequencies of the test curve shall not exceed 32 dB (on average, 2 dB per frequency)



After the IIC contour is adjusted to meet the above listed limitations the IIC rating is read as the vertical number on the right that corresponds with the 500 Hz coordinate. For the purposes of my acoustical analysis, I will be using the IIC ratings the *Catalog of STC and IIC Ratings for Wall and Floor/Ceiling Assemblies*, issued by the California Department of Health Services.

Existing Assemblies

Floor Assemblies

As stated earlier, each floor system in the structure consists of W-shape steel members supporting 4.5" of concrete on 2" metal deck (6.5" total). The only variant anywhere in the building is the floor covering. In the bookstore areas, the floor covering is not specified. In this case the bookstore, from my perspective, can be assumed to have either a low carpet or wood flooring. Thus, both possibilities will be considered.

Wall Assemblies

For the three walls in question, there are two different wall types in use. The aerobic/office wall and the MEP/fitness wall are both type 1 walls which consist of:

- 3-5/8” x 25 gage metal studs @ 16” o.c.
- 5/8” gypsum board, each side
- 3” minimum sound attenuation blanket

The wall separating 4th floor gymnasium and studio is type 1A which consists of:

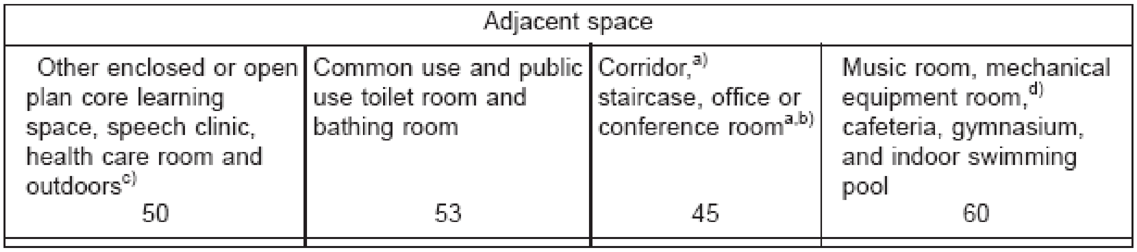
- 6” x 20 gage metal studs @ 16” o.c.
- 5/8” gypsum board, each side
- 3” minimum sound attenuation blanket

Required/Existing STC and IIC ratings

Required STC Wall Ratings

In researching minimum requirements for wall assemblies, many sources of differing reliability surfaced. Of the many I have found, two presented themselves as both reliable and accurate. First, Egan’s Architectural Acoustics text contains a table for STC ratings in schools. The table is a good starting place and a reliable source if no more specific information could be found. Another reference that will be used to judge the appropriateness of the wall systems herein will be ANSI S12.60-2002, the *American National Standard for Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools.* This standard provides guidelines and minimum STC ratings for new school classrooms and other secondary learning spaces. A third source of STC requirements for spaces is the *U.S. Army Physical Fitness Facilities Criteria*, issued by the Corps of Engineers.

Table 2 — Minimum STC ratings required for single or composite wall, floor-ceiling, and roof-ceiling assemblies that separate an enclosed core learning space from an adjacent space



Adjacent space			
Other enclosed or open plan core learning space, speech clinic, health care room and outdoors[c)]	Common use and public use toilet room and bathing room	Corridor,[a)] staircase, office or conference room[a,b)]	Music room, mechanical equipment room,[d)] cafeteria, gymnasium, and indoor swimming pool
50	53	45	60

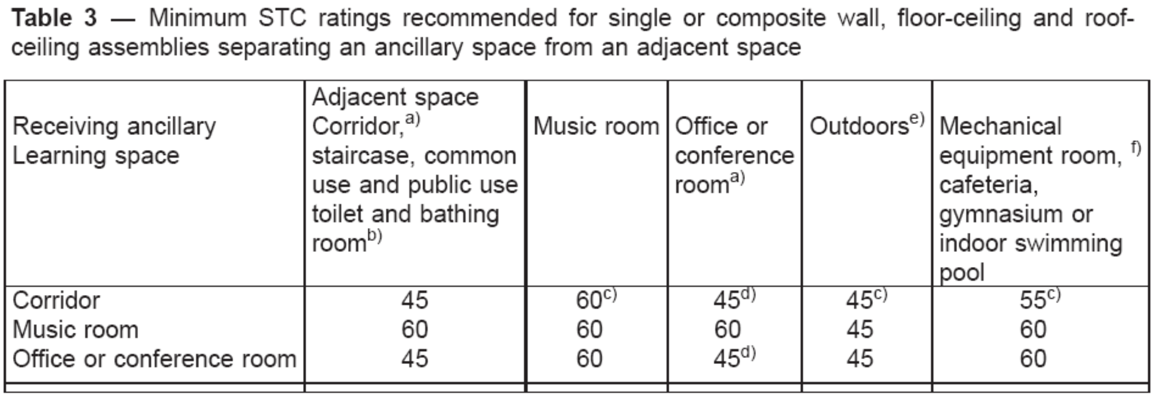
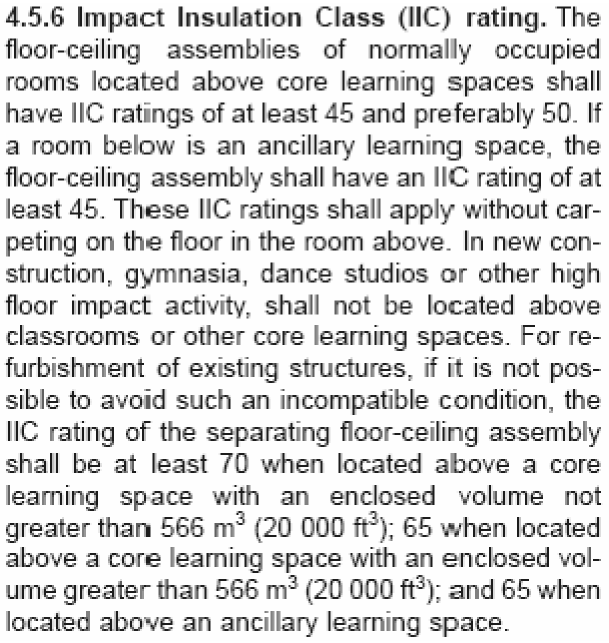


Table 3 — Minimum STC ratings recommended for single or composite wall, floor-ceiling and roof-ceiling assemblies separating an ancillary space from an adjacent space

Receiving ancillary Learning space	Adjacent space Corridor,[a] staircase, common use and public use toilet and bathing room[b]	Music room	Office or conference room[a]	Outdoors[e]	Mechanical equipment room,[f] cafeteria, gymnasium or indoor swimming pool
Corridor	45	60[c]	45[d]	45[c]	55[c]
Music room	60	60	60	45	60
Office or conference room	45	60	45[d]	45	60

Required IIC Floor Ratings

The IIC floor ratings will be taken from the Egan Architectural Acoustics text, IIC Ratings for Dwellings. For the purpose of this exercise, the highest rating in this chart will be assumed to be quite sufficient for each analysis. The ANSI standard used for the STC ratings will be consulted as well, as the recommended IIC rating for a receiving classroom is “at least 45 and preferably 50." (Below is the ANSI passage referring to IIC)

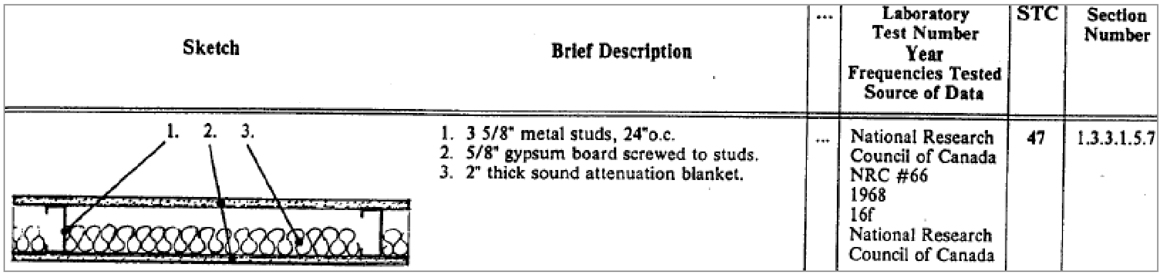


4.5.6 Impact Insulation Class (IIC) rating. The floor-ceiling assemblies of normally occupied rooms located above core learning spaces shall have IIC ratings of at least 45 and preferably 50. If a room below is an ancillary learning space, the floor-ceiling assembly shall have an IIC rating of at least 45. These IIC ratings shall apply without carpeting on the floor in the room above. In new construction, gymnasia, dance studios or other high floor impact activity, shall not be located above classrooms or other core learning spaces. For refurbishment of existing structures, if it is not possible to avoid such an incompatible condition, the IIC rating of the separating floor-ceiling assembly shall be at least 70 when located above a core learning space with an enclosed volume not greater than 566 m^3 (20 000 ft^3); 65 when located above a core learning space with an enclosed volume greater than 566 m^3 (20 000 ft^3); and 65 when located above an ancillary learning space.

Existing STC Wall Ratings

Wall #1: 2nd floor aerobic/office

- 3-5/8” x 25 gage metal studs @ 16” o.c.
- 5/8” gypsum board, each side
- 3” minimum sound attenuation blanket



Sketch	Brief Description	...	Laboratory Test Number Year Frequencies Tested Source of Data	STC	Section Number
1. 2. 3.	1. 3 5/8" metal studs, 24"o.c. 2. 5/8" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	...	National Research Council of Canada NRC #66 1968 16f National Research Council of Canada	47	1.3.3.1.5.7

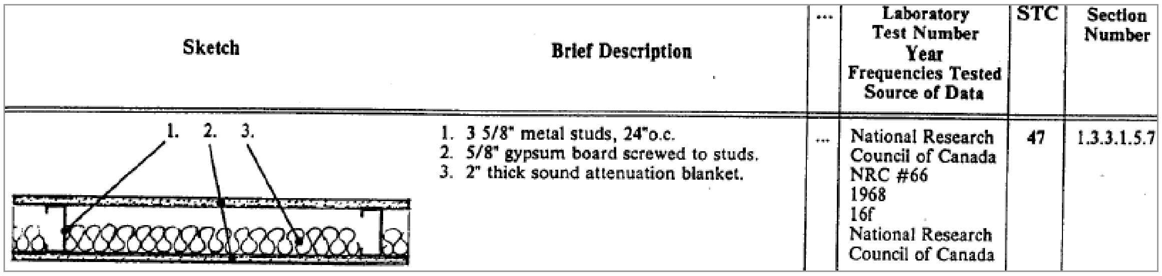
*Assume stud spacing does not affect STC

The criterion for the ANSI standard for secondary facilities (i.e. an office) is an STC rating of 60. However, the source room is not specified and is left open to 5 different sound producing possibilities. The U.S. Army criterion has an aerobic room STC requirement of 53. Similarly, the Army requirement for a private office is STC 50-53. Therefore, the wall construction shown here is inadequate. According to the Egan text, adding at least 2” of sound absorbing material could boost the STC value by 4-8 points. If that is not an option, adding an extra later of gypsum board will also increase the STC rating. Also, the above rating is for a 24” stud spacing and not 16”. This will affect the STC level by at least 1-2 rating points.

Existing STC:	**47-49**
Add 2” sound blanket:	**+ 4-8**
Total STC:	**51-57**
U.S. Army Required STC:	**53**

Wall #2: 2nd floor MEP/fitness

- 3-5/8” x 25 gage metal studs @ 16” o.c.
- 5/8” gypsum board, each side
- 3” minimum sound attenuation blanket

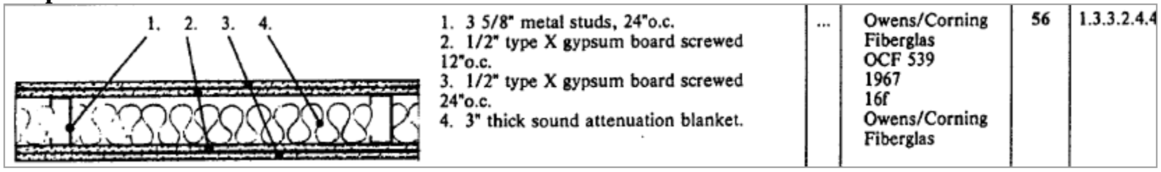


Sketch	Brief Description	...	Laboratory Test Number Year Frequencies Tested Source of Data	STC	Section Number
1. 2. 3.	1. 3 5/8" metal studs, 24"o.c. 2. 5/8" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	...	National Research Council of Canada NRC #66 1968 16f National Research Council of Canada	47	1.3.3.1.5.7

*Assume stud spacing does not affect STC

Existing STC: **47-49**

Proposed Construction:



1. 2. 3. 4.	1. 3 5/8" metal studs, 24"o.c. 2. 1/2" type X gypsum board screwed 12"o.c. 3. 1/2" type X gypsum board screwed 24"o.c. 4. 3" thick sound attenuation blanket.	...	Owens/Corning Fiberglas OCF 539 1967 16f Owens/Corning Fiberglas	56	1.3.3.2.4.4

Upgrade to 5/8” gyp. Board: **+2-3**
ANSI Required STC: **55-60 (ancillary learning space)**
U.S. Army Required STC: **55**

Wall #3: 4th floor gymnasium/studio

- 6” x 20 gage metal studs @ 16” o.c.
- 5/8” gypsum board, each side
- 3” minimum sound attenuation blanket

Since the catalog at my disposal has only 1-5/8” through 3-5/8” metal studs, I cannot directly compare this construction to an available value. However, in seeing the last assembly being rated at STC 56, I believe this construction would be rated at an STC of over 60.

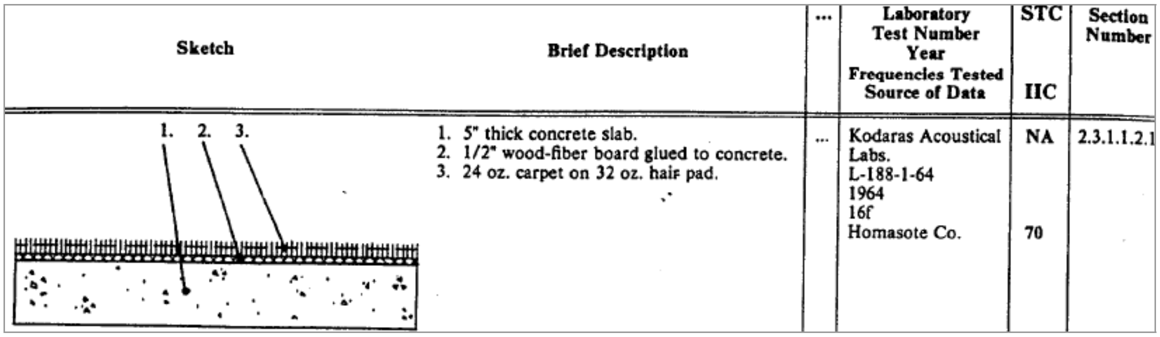
Estimated STC: **> 60**

ANSI Required STC: **60**
U.S. Army Required STC: **53 office**
55-60 fitness/gym

Existing IIC Floor Ratings

Floor #1: Watson bookstore/Forbes bookstore

- W16 and W18 framing members
- 4.5” NWC on 2” composite metal deck
- Carpeting on rubber pad
- ACT ceiling in bookstore

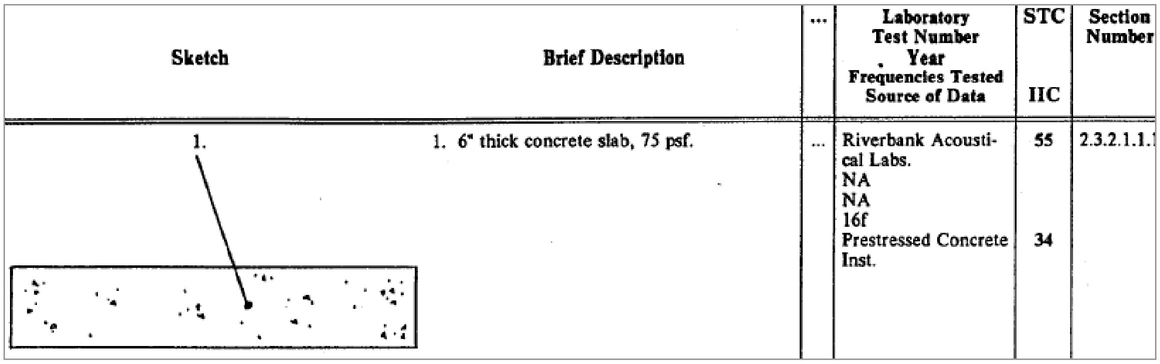


Sketch	Brief Description	...	Laboratory Test Number Year Frequencies Tested Source of Data	STC IIC	Section Number
1. 2. 3.	1. 5" thick concrete slab. 2. 1/2" wood-fiber board glued to concrete. 3. 24 oz. carpet on 32 oz. hair pad.	...	Kodaras Acoustical Labs. L-188-1-64 1964 16f Homasote Co.	NA 70	2.3.1.1.2.1

IIC from chart: **70**
ANSI Required IIC: **65**

Floor #2: 3rd floor gym/2nd floor classroom

- W16 framing members
- 4.5” NWC on 2” composite metal deck
- Rubber athletic floor on rubber base
- ACT ceiling in classroom



Sketch	Brief Description	...	Laboratory Test Number Year Frequencies Tested Source of Data	STC IIC	Section Number
1.	1. 6" thick concrete slab, 75 psf.	...	Riverbank Acoustical Labs. NA NA 16f Prestressed Concrete Inst.	55 34	2.3.2.1.1.1

Summary and Conclusions

Revisiting my first investigation, the least weight and most cost effective lateral system made use of HSS members in a chevron bracing configuration. Because, the system is located on the exterior of the structure, the beams in each frame must support the masonry façade at each floor level. The masonry deflection limits of L/600 or 0.3" controlled the design of each member. The chevron braces, connected at the center of each beam, decrease each span by half. This reduction in span greatly reduces the lateral frame beam sizes without compromising their load carrying capacity within the frame.

Looking back on each lateral system, choosing one over another is a matter of architectural needs, location of lateral frames, and total engineering time. Designing a concentric system with braces used for their tension capacity only, is an attractive option because it eliminates compression related design issues such as effective length and buckling. In this particular case, I would recommend the use of the alternate chevron bracing scheme.

Depending on building use and occupancy, the need to prescribe strict vibration criteria is a debatable issue. In the case of the Duquesne University Multipurpose Athletic Facility, the name says it all. The building is used to house athletic and office type facilities, and should be designed to comfortably accommodate both. With that in mind, each of four floors was redesigned to the standards laid out in AISC Design Guide 11. The redesign yielded a building that is both vibrationally sound and yet, cost feasible. This is made possible because of the economical capabilities of castellated beam members used in long span areas. Because the cost of the alternate design is within $20,000 of the existing structure, I would recommend that the alternative design be used (assuming the structure had yet to be built).

On the subject of personal comfort, acoustical properties of interior spaces were also taken into consideration. The construction of most all critical interior walls that separate active and inactive spaces is satisfactory. Only in a few instances did the assembly not meet sound transmission criteria. At these walls, adding an extra layer of gypsum board or a thicker sound attenuation blanket would be a quick, effective fix. The floor/ceiling assemblies throughout the building (6.5" concrete slab and composite steel framing) are satisfactory in regards to sound related issues.

Throughout the research and design process, I have tried to improve the overall performance of the structure while reducing, or maintaining existing cost values. I feel that each alternate system proposed, whether for lateral or gravity loads, is an effective solution both in terms of structure and cost.

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RS Means Building Construction Cost Data 2007

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Calculation Appendix

Detailed calculations or design data of or relating to the following are available upon request:

- Lateral Load Determination
- Relative Stiffness and Torsion Calculations
- RAM Advanse Input
- RAM Structural System Models
- Vibration calculations
    - Rhythmic criteria per AISC Design Guide 11
- Castellated Beam design
    - Per CMC Steel design aides
- Detailed Building Cost Estimates
    - Material
    - Delivery
    - Labor/Erection
    - Equipment