A REPORT ON VIBRATION CONTROL
PHYSICS AND NANOTECHNOLOGY BUILDING
UNIVERSITY OF MINNESOTA
MINNEAPOLIS, MINNESOTA

ESI Project 1721
November 15, 2011 (Rev. 1)

Prepared For:
Ms. Ellen Olson, AIA
Architectural Alliance
400 Clifton Avenue South
Minneapolis, Minnesota 55403-4135
Tel: D. 612-874-4135

Prepared by:

Carl A. Nelson, Ph.D., P.E.

ESI ENGINEERING, INC.
7831 Glenroy Road, Suite 430
Minneapolis, Minnesota 55439
Tel (952) 831-4646
Fax (952) 831-6897
esi-engineering.com
1 SUMMARY

This report presents the analysis of vibration due to footfall in the laboratory spaces of the new Physics and Nanotechnology Building at the University of Minnesota. It is shown that the structural design of the lab floors is predicted to provide effective vibration control down to the level of 2000 micro-in/sec for a walker at 75 steps per minute. Analysis of the cleanroom slab is presented in a separate report.
2 INTRODUCTION

Architectural Alliance and ZGF Architects are leading the design of the new Physics and Nanotechnology building. The new building comprises 43,000 square feet of flexible laboratory and cleanroom space. The facilities are housed on four levels, plus a basement and a penthouse level. Figure 2-1 shows a view of the building taken from the University’s website.

ESI Engineering is providing vibration control engineering for the project. ESI’s scope of work included help in establishing design goals for the various spaces, performing structural vibration analyses, measuring current vibration levels at the site, consulting with the structural engineer and architect, and recommending special materials or construction details.

![Figure 2-1. View of the Physics and Nanotechnology building from the southwest.](image)

Meyer Borgman Johnson is the structural engineering firm on the project. The structural slabs are concrete pan and joist. A wide module pan and joist system with a 5-inch slab and 25 inch total depth has been selected for the structural system. Bay sizes are 22 feet in the north-south direction. In the east-west direction, the bays are 32, 33, 44, and 43 feet from west to east.

The 24-in thick cleanroom floor system is supported on an extensive array of drilled piers reaching down to the limestone bedrock approximately 50 feet below grade. Vibration measurements were taken to characterize the ground-borne vibration at the site. ESI recommended a cleanroom slab that is isolated from the ground with an air space below, in order to mitigate vibration from external sources such as vehicular traffic. It consists of a precast lower section with a cast-in-place slab placed over it to form a monolithic thick slab.

During the course of the design, ESI worked with MBJ in both the elevated slab design and the cleanroom slab design to evaluate various options and identify vibration mitigation solutions. Numerous options in both areas were evaluated. ESI reviewed and evaluated the expected vibration of the structural slabs using techniques published in AISC Design Guide 11 and other similar references. This report deals with the structural (non-cleanroom) slabs only. The cleanroom slab analysis is summarized in a separate report.
3 VIBRATION CONTROL

Vibration from any source has the potential to be noticeable and intrusive to people in buildings. When sensitive equipment is located in buildings, the function of the equipment may be affected by excessive vibration. The following sections in this report present the analysis of floor vibration caused by people walking, also known as footfall vibration.

3.1 Vibration Criteria

References 1 through 3 contain the applicable vibration criteria for sensitive equipment. For the Physics and Nanotechnology building, the allowable vibration for the laboratory floors was established at 2000 micro-in/sec during Design Development. A much more restrictive criterion was established for the cleanroom floor.

The laboratory criterion corresponds to the VC-A curve shown in Figure 3-1. Reference 1 describes this criterion as “adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity and projection aligners, etc.” The VC-A curve has been specified in other research facilities with successful outcomes. Should a more restrictive criterion be required for specific pieces of sensitive equipment, the equipment may be isolated by means of special isolation platforms or tables, or can be located near columns.

As shown in the Figure 3-1, the VC-A curve is at a constant velocity of 2000 micro-in/sec for frequencies greater than 8 Hz, and increases linearly with decreasing frequency on a log-log scale. The straight line between 4 and 8 Hz corresponds to a constant acceleration of 250 micro-g’s, where g is the acceleration of gravity.

Figure 3–1. Criteria curves for sensitive equipment and human comfort.
3.2 Description of Floor Plan

The area of the building that was analyzed for footfall vibration is shown in Figure 3-2. The 4th Level was chosen as representative of the laboratory space. It includes the spaces identified as the Cushman and the Cronin Hennessey Laboratories, which are located on 44 and 43 foot spans. A north-south corridor runs between these two labs just east of Grid D. In addition, the HEP CMS Lab is located to the north, also on a long span.

Figure 3–2. Level 4 laboratory area analyzed for footfall vibration.
3.3 Description of Structure

The 40% DD Level 4 framing plan is shown in Figure 3-3. Initially, the two long bays were designed with three bridging members between adjacent joists. This system was subsequently modified slightly as shown in Figure 3-4 to reduce the number of cross members. Post tensioning was employed in the joists in the 44 and 43 foot bays in order to increase the stiffness in these bays. The bridging members were eliminated in the two shorter bays. The framing consists of a wide module pan and joist system with a 5-inch slab and a total depth of 25 inches. Joist spacing is 5.5 feet in most bays. Joist width is 12” with 16” wide joists on the column lines. Concrete strength is 6000 psi.

Figure 3–3. Level 4 framing (40% DD).
Figure 3–4. Final Level 4 framing, showing areas with post-tensioned joists.
3.4 Finite Element Model Description

COSMOS/M Version 2.9, from Solidworks. (Dassault Systèmes) was used for the finite element model (FEM). The FEA model shown in Figure 3-5 was constructed by ESI to analyze footfall and includes the sensitive areas of Level 4 laboratory space. The effective moments of inertia for the joists were calculated using the ACI method based upon estimated service load moments at the ends and mid-span of the beam, combined with the gross and cracked moments of inertia. For the post-tensioned joists, this procedure provides a conservative value for the effective moment of inertia. The concrete slab was modeled with plate elements with the density adjusted to include a live load of 20 psf and a mechanical/equipment load of 10 psf.

The impulse-based analysis of Chapter 6, Design Guide 11 (Ref. 4), was employed. This analysis is based upon static deflection (flexibility) at the receiver due to a unit vertical load at the walker. Floor frequency is determined with a harmonic analysis of the walker-receiver combination, using the frequency at which peak response occurs at the receiver due to a unit harmonic load at the walker.

In order to model the effect of walking, a moderate walker (75 spm) was placed in the worst case location. In all cases the walker, represented by vertical point load, was assumed at the center of a structural bay to obtain the most severe static deflection. The selection of 75 steps per minute is based upon the discussion by Murray in Reference 5.

Figure 3–5. Finite element model of Level 4 pan and joist structure.
3.4.1 Footfall Analysis Results

Ten nodes were chosen to evaluate critical locations for footfall as shown in Figure 3-6. The locations were chosen mostly on the two long spans on the east side of the building.

![Finite element model of Level 4 pan and joist structure.](image)

*Figure 3–6. Finite element model of Level 4 pan and joist structure.*

The results of the footfall analysis for each of the locations are provided in Table 3-1. It is seen that the predicted floor velocity is below the allowable floor velocity of 2000 micro-ips for all of the scenarios analyzed. The highest vibration levels are predicted to be at Node 2594 (Cushman Lab) and Node 407 (HEP CMS Lab).

The results are presented graphically in Figure 3-7.
Table 3-1. Predicted Vibration due to Footfall

<table>
<thead>
<tr>
<th>Node</th>
<th>Flexibility (micro-in/lb)</th>
<th>Frequency (Hz)</th>
<th>Velocity (micro-in/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>887</td>
<td>1.58</td>
<td>7.45</td>
<td>1175</td>
</tr>
<tr>
<td>888</td>
<td>1.90</td>
<td>7.50</td>
<td>1403</td>
</tr>
<tr>
<td>889</td>
<td>1.83</td>
<td>7.41</td>
<td>1368</td>
</tr>
<tr>
<td>407</td>
<td>2.29</td>
<td>8.22</td>
<td>1543</td>
</tr>
<tr>
<td>180</td>
<td>2.02</td>
<td>11.00</td>
<td>1017</td>
</tr>
<tr>
<td>2030</td>
<td>1.83</td>
<td>9.14</td>
<td>1109</td>
</tr>
<tr>
<td>494</td>
<td>2.12</td>
<td>11.80</td>
<td>995</td>
</tr>
<tr>
<td>3030</td>
<td>1.93</td>
<td>11.90</td>
<td>899</td>
</tr>
<tr>
<td>2594</td>
<td>1.92</td>
<td>7.41</td>
<td>1435</td>
</tr>
<tr>
<td>2595</td>
<td>2.01</td>
<td>9.18</td>
<td>1213</td>
</tr>
</tbody>
</table>

The results are presented graphically in Figure 3-7.

Figure 3–7. Predicted footfall vibration vs. frequency.
4 REFERENCES


