Design Live Loads for Office Gathering Spaces

By

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ABSTRACT

Dating back to the 1800's, there have been live load surveys and analyses, particularly of area-dependent loads in office buildings. While some occupancies have received careful examination, there has been no systematic review and consideration of reliability-based scenarios for office gathering space live loads. The results of the research reported here indicates (supports) a more consistent, reliable and economic design load for office gathering spaces in buildings. These results provide the theoretical and practical basis for design live loads for gathering spaces within offices, a step toward possible enactment in the ASCE/SEI 7 Standard, and subsequently by adoption into the International Building Code and materials standards. Following a review of historical load surveys and theoretical models, the paper presents models and observations of crowding, serving as a basis for a different approach for such areas, including a Delphi among leading design firms in the United States. The paper concludes with recommendations for a new live load use category for gathering spaces for offices.

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PRACTICAL APPLICATIONS

Modern office usage often contains work spaces for meeting, gathering and collaboration. The current ASCE/SEI 7 Standard Minimum Design Loads and/Associated Criteria for Buildings and Other Structures [2022] does not directly address this situation. Interpretation has led to conflicting requirements for the design loads of such spaces, including the possibility of assigning them as assembly areas. This can lead to overdesign and uneconomical structures. This research reviews historical office surveys with an emphasis on assembly spaces, presents the results of a Delphi of design firms throughout the United States, and contains a stochastic maximum load analysis. These various assessments lead to a consistent evaluation of plausible loads for such spaces, and a recommendation for a new sub-category under the Office Loads heading in the ASCE/SEI 7 Standard live load table. The study recommends treating these spaces similar to general offices, with a basic live load of 2.39 kN/m2 (50 psf), and permissible live load reduction as is currently in the Standard for offices. Exception is made for such work spaces that are directly accessible from outside and intended for use by the general public.

1. INTRODUCTION

Dating back to the 1800’s, there have been live load surveys and analyses, particularly of area-dependent loads in office buildings. There has been no systematic review and consideration, however, of reliability-based scenarios for assembly loads, and in particular the implications for office gathering spaces, which are now common in many firms. Such spaces are becoming more common, and include traditional conference rooms, but also more open spaces in the office used for collaboration and casual interactions among employees. The driving rationale for the present study, therefore, is a modern contemplation of these loads. It is hoped that an innovative, modern approach to reliability-based design live loads for gathering spaces in buildings will be a catalyst for improved safety and efficiency in design, enhanced consistency, and more reliable and economic design, including reduction of carbon footprints due to lower use of construction materials. As will be shown, while some occupancy loads have received careful examination, loads for assembly areas has almost been an afterthought. This was likely due to three factors:

1) Due to historically heavy construction dead loads, the code requirement for live loads was not as significant a design factor;
2) surveys could not capture the situations that led to crowded conditions for assembly, and without such survey data there was a reluctance to speculate on maximum likely assembly loads over a building's design lifetime; and
3) Fixed layouts of building use meant designing only limited areas for the heavier assembly loads.

All three factors have changed. Lighter designs have increased the ratio of design live loads to dead loads, logical probability-grounded scenarios have paved the way for reliability-based design (as, for instance, with performance based seismic design values of the maximum considered earthquake, MCE), and flexible design and nonstructural partitions have increased the demand for adaptable future usage of building space. It is the time for a different approach to design floor loads for assembly areas; survey data and extrapolation visualization estimates do not represent the most realistic concept for design of these areas. Probabilistic-based assignment of design loading can lead to increased efficiency and safety by enabling the variability of the loads to which the structure is subjected and the inherent uncertainty in the material strength and failure modes to be incorporated into a reliability analysis.

2. REVIEW OF PRIOR SURVEYS – FOCUS ON ASSEMBLY AND GATHERINGS

In order to portray a sense of the accuracy in this review of prior surveys, results are in the units actually obtained from the survey, followed by alternate units in parentheses.

Blackall – 1893

Blackall conducted and published one of the first live load surveys [Blackall, 1893]. He reported on surveys of three office buildings in Boston, Massachusetts. While he did not address assembly areas, he did refer to an experiment conducted earlier that year in which it was determined that it was possible to crowd enough people together to form a load of 7.18 kN/m^2 (150 psf). He accomplished this by crowding 58 laborers into a space of 5.3 m^2 (57 square feet). In his 1893 paper Blackall states, "…it by no means follows that the floors of a hall of audience should be calculated for a live load of 7.06 kN/m^2 (147.4 pounds per foot), for the reason that there never had been a hall of audience into which people could be packed at that rate." He goes on to say that from his observations of "theatres and music-halls", he has not seen an average load exceeding forty or fifty pounds per square foot extended over more than a few square feet, even with "crowded aisles and standing-room". Even at that time there was concern of over-conservative design, with the author stating, "…with the enormous buildings of twelve to thirty stories in height, …a difference in assumption of ten pounds per foot would make a difference of thousands of dollars in the cost of the completed building." The remainder of Blackall's published article refers to the survey of three office buildings in Boston, and does not again address the crowding of people in assembly areas.

Blackall – 1923

Thirty years later Blackall again addressed live loads, with a new survey of a building in Boston [Blackall, 1923]. He took the most heavily loaded office out of 64 surveyed, considered the furniture piled into minimum floor space, and bunched people together at two square feet per person. He concluded that the load would not exceed 2.39 kN/m^2 (50 psf). Blackall also notes the lighter loads in "modern" offices in 1923 as compared to those of 1893. He concludes that while the slabs forming an office floor should be constructed for a load of 4.79 kN/m^2 (100 pounds per square foot), "I can see no reason for proportioning the girders for over 30 pounds per foot (1.44 kN/m^2), and I would carry this unit load down through the columns in all stories." Blackall notes that his recommendation would increase the cost of floor slabs, since the Boston code at the time required a minimum design of 3.59 kN/m^2 (75 psf), but that this would be more than offset by the savings in girders and columns.

Department of Commerce – 1923

The Department of Commerce reported on a survey of several floors of an office building in New York City (the Equitable Building, "well known as perhaps the largest office building in the world [Department of Commerce, 1923; Woolson, 1923]". Unfortunately, there was no attempt to document crowding of personnel. The referenced article mentions small surveys in Cincinnati, Ohio and one reference room in a New York insurance building. That latter survey noted that the room “showed it liable to use by no more than 12 men simultaneously,” leading to a total “occasioned” load of 2.41 kN/m^2 (50.3 psf) which then became a de facto value for offices. As with Blackall’s studies, he assumed 68 kg (150 pounds) as the weight of an individual, but this report does note that this figure “is probably too high, as a considerable portion of such occupants is females, whose weight probably would not exceed 54 kg (120 pounds).” The Department of Commerce study stipulates that offices should be designed for the 2.39 Kn/m^2 (50 psf) that is still in use today, along with the concentrated load to account for an office safe. The article does make mention of a study on people “in congested and freely moving masses,” by a Professor L.J. Johnson, apparently a civil engineering professor at Harvard University and later the Massachusetts Institute of Technology, but no further reference to publication of this work could be found.

Department of Commerce – 1945

This marked the publication of the first building load standard by the National Bureau of Standards [National Bureau of Standards, 1945], which was the forerunner to the standard ANSI A58, which later became ASCE/SEI 7 [2022]. It was a report by Sectional Committee A58. Unfortunately, neither the body of the standard nor the commentary introduces new information on crowding.

The recommended uniformly distributed floor load for offices was 3.83 kN/m^2 (80 psf), a reduction in the commonly used 4.79 kN/m^2 (100 psf) previously. A value of 2.39 kN/m^2 (50 psf) had been recommended in the 1923 Department of Commerce study, but without any live load reduction, except 10% per floor for columns. The increase from 2.39 to 3.83 kN/m^2 (50 to

80 psf) for offices was associated with an offsetting new live load reduction formula. Lobbies were kept at 4.79 kN/m^2 (100 psf), as were assembly areas with movable seats, corridors on upper floors, dance halls, balconies, fire escapes, public rooms and stairways. Without new data, it appears that the office values came from an analysis of the prior surveys, and assembly areas simply left intact. The live load reduction for loads of 4.79 kN/m^2 (100 psf) or less stipulated that "…public-assembly occupancies, such as theaters, must be assumed to be fully occupied under normal conditions, and reduction would be unwarranted."

Dunham – 1947

Dunham reported the next live load survey of note [Dunham, 1947]. He surveyed several buildings in Washington, DC, but most were warehouses. There is no attention to areas of assembly, except a repeat almost verbatim of the quote cited above in the Department of Commerce report. In Dunham's closure to discussion, however, he does make the statement, "The probability of overloading an office building with people is remote."

Dunham, Brekke and Thompson 1952

The National Bureau of Standards issued its next report of live loads on building floors in 1952 [Dunham et al, 1952], based on further analysis of the work initiated by Dunham, as well as additional surveys. The article also refers to a 1924 out-of-print report for the Department of Commerce that addressed "crowded rooms." That article pointed out that while it was possible to obtain loads of 6.70 kN/m^2 (140 psf) or greater, these were from unlikely methods. Actual observations of the elevators in the Grand Central Terminal in New York showed a maximum of 73 persons in 8.5 m^2 (92 square feet). Assuming a gender-weighted average of 59 kg per person

(130 pounds), this led to 4.79 kN/m^2 (100 psf). A similar study of students crowded onto a balcony gave 5.55 kNm^2 (116 psf). There is no further discussion of assembly areas, but from this and prior studies one can conclude that loads of 4.79 kN/m^2 (100 psf) are restricted to small areas of unusual occupancy, and would be considered over-conservative for girders and columns supporting larger areas.

Jauffred - 1960

Jauffred [1960] reported on live loads in the federal district of Mexico for dwelling and office units. Results indicated the suitability of a normal probability distribution for furniture and an extreme value type I distribution for persons. The survey asked occupants to report the maximum load due to persons, and over what period of years. The survey comprised a total of 180 dwelling units and 81 offices (a total office area of 12,362 m^2 (133,063 ft^2). For offices, it was found that for the day of maximum loading, the load that had a 5% probability of being exceeded rarely was higher than about 1.92 kN/m^2 (40 psf) for bays around 100 m^2 (1080 ft^2), and less for smaller bays.

Kàrmàn – 1969

Kàrmàn [1969] conducted a large survey of live loads in Hungary. The author clearly states that the surveys only included regularly acting loads, and not the “occasional gathering of persons,” he does present recommendations for the latter, described as estimations. The analysis includes a distribution of time between occupancy changes, and lifetime maximum statistics based on repeated exposures. With respect to temporary accumulation of people, the report references a 1953 thesis by Arne Ivan Johnson [1953], asking 335 residents of dwellings to recall the maximum occasional loads over a period of ten years. Unfortunately, the 219 reliable responses are not relevant for assembly areas in office buildings, for instance. The 10-year maximum reported by Johnson over an assumed area of 30m^2 (323 ft^2) averaged about 0.29 kN/m^2 (6 psf), with a standard deviation of 0.14 kN/m^2 (3 psf). An interesting side point from Johnson's survey is that he found an expected 50-year maximum load for offices to be about 2.44 kN/m^2 (51 psf), essentially the same as ASCE/SEI 7 [2022].

Bryson and Gross – 1968; Culver – 1976; Ellingwood and Culver – 1977

The National Bureau of Standards (NBS) of the Department of Commerce conducted a live load survey in 1968 [Bryson and Gross, 1968; Culver, 1976]. It was restricted to office buildings, and consisted of two federal buildings around Washington, DC. The surveys were limited to observed conditions of equipment, movable partitions and occupants, with no consideration of occupancy loads under crowding conditions. Subsequent analyses by Ellingwood and Culver [1977] compared results to the Mitchell and Woodgate [1971] survey and developed approaches for code live load values. Due to limitations of both surveys, crowding models were not included in the data, although Ellingwood and Culver [1977] based subsequent discussion of extraordinary loads on earlier models by Peir and Cornell [1973] and by McGuire and Cornell [1974].

Mitchell and Woodgate – 1971

The NBS study referenced above was followed shortly thereafter by the report of a survey of floor loads in office buildings conducted in London, England [Mitchell and Woodgate, 1971]. They conducted the survey under conditions of normal occupancy. An interesting side note is that the survey revealed the average male weighed 71 kg (157 pounds) and the average female weighed 61 kg (134 pounds), modest increases from assumed values almost a century earlier. The team further considered the situation of fire drills, with crowding at "stair heads or at doorways across corridors." Based on studies conducted by the London Transport Board, they concluded that packing of personnel to the point of no shuffling created a loading of 2.39 kN/m^2 (50 psf).

Dayeh – 1981

This conference paper [Dayeh, 1981] was originally an unpublished report for the Experimental Building Station in New South Wales, Australia in 1974. It includes a live load survey of a twenty-story office building in Australia. In the unpublished report, the author notes that he obtained information from the occupants for "Extraordinary Loads" due to crowding, with the observation that those compose only about 10% of the total load. Clearly, this was not an attempt to estimate crowding conditions.

Kanda and Kinoshita – 1985

This study [Kanda and Kinoshita, 1985] reported on the survey of 19 office buildings in Japan (14 by inventory and 5 by actual field surveys. Unfortunately, they gathered no information on crowding.

MEICON – 2018

This study [MEICON, 2018] surveyed 129 individuals (115 of which were structural engineers), principally in the United Kingdom, regarding overdesign of structures, and the consequent inefficiency of building construction and increased contribution to carbon emissions. The acronym for the study stands for Minimising Energy in Construction. The study asked individuals their opinions regarding floor design loads, among other questions. Survey results indicated that there was general agreement that code-specified floor load values were appropriate. The vast majority responded that characteristic values of floor loads in a multi-story office buildings should be in the range of 2.5-3.0 kN/m^2 (50-65 psf), although about 15% of respondents indicated about (4.0 kN/m^2 (85 psf). Respondents estimated average floor loads over the lifetime of the structure to be in the range of 1-2 kN/m^2 (20-40 psf), and maximum loads over an assumed 60-year design life as 2-3 kN/m^2 (40-65 psf), but with about 10% of respondents indicating about 4 kN/m^2 (85 psf). There were no instructions to the respondents in terms of estimating the maximum loads.

It is interesting to note that office floor loads in London were specified in 1909 to be 4.79 kN/m^2 (100 psf), and continued around that value for about a decade, after which they started to decrease. They have been around 2.39 kN/m^2 (50 psf) for the past half century. The MEICON study reports data from real estate agencies of floor loads averaging 4.48 kN/m^2 (94 psf) including partitions; not substantiated in the report and is highly questionable. Current London code values vary between 2 and 3 kN/m^2 (41.8-62.7 psf), with the British Council for Offices specifying 2.5 kN/m^2 (52.2 psf) for above ground floors [British Standard 6399, 1996].

3. THEORETICAL MODELS OF BUILDING LIVE LOADS

Horne 1951

This theoretical study introduced the concept of reducing floor loads as a function of area supported, and utilized the survey results of Dunham 1946 [Horne, 1951]. He did not calibrate the assumed model, however, and did not include any consideration of crowding.

Corotis et al – 1972-1985

Corotis and his students developed live load models for applications to design codes [Chalk and Corotis, 1980; Corotis, 1972, 1985; Corotis and Doshi, 1977; Corotis et al, 1981; Corotis and Jaria, 1979; Harris et al, 1981; Jaria and Corotis, 1979; Corotis and Tsay, 1983], and in one case conducted a live load survey of a hospital [Harris and Corotis, 1978]. They based models on the results of prior surveys, and developed the crowding modeling to represent events such as parties and meetings. They proposed live load reduction formula that is still use in ASCE/SEI 7 [2022]. None of these studies specifically addressed the unusual crowding applicable to assembly occupancy.

Peir and Cornell – 1973 and McGuire and Cornell – 1974

These studies [Peir and Cornell, 1973; McGuire and Cornell, 1974] did not actually conduct a survey, but instead developed a theoretical model for repeated sustained loads, unfortunately not including crowding. They did include an extraordinary load modeled as randomly distributed cells, with people in each cell. This might be considered as the first attempt at a “crowding” model. They calibrated models for code comparison, but did not develop the theory for gatherings of people or for assembly areas.

Sentler – 1975 and 1983

In this report [Sentler, 1975], the author notes that transient live load surveys do not provide an adequate base for the adoption of a model, but rather judgement is necessary. He assumes that the average transient load intensity at any point on a floor is position-independent, but the transient load is a spatial random process in both space and time. That provides a load that is dependent on area, leading to a lower unit load with increasing area, and an increasing expected load over time of exposure. He notes that survey results are unavailable, and questioning of interviewees is inaccurate. He uses interview data from a prior survey in Finland [Paloheimo and Ollila, 1973], but these led to average crowds of less than one person per square meter in general, which is obviously not of value for assembly area design values. Sentler later [1983] simplifies the model to provide a constant mean value as a function of area, and states that values must be "estimated from reasonable assumptions."

4. MODELS AND OBSERVATIONS FOR CROWDING OF PEOPLE

MEICON

The MEICON [2018] study discussed earlier had a section specifically addressing crowding of people. This report recognized that estimates of maximum loading from experience might not be a reliable method to determine design loads. As such, they presented a figure (Figure 6 in this paper), taken during the 50-year celebration of the opening of the Golden Gate Bridge in San Francisco. It is not clear whether they showed respondents the photograph before answering. It has been speculated that this celebration caused the largest load ever seen on the bridge, and was estimated to be 2.87 kN/m^2 (60 psf), which will be discussed subsequently.

Situations such as shown for the bridge raise the obvious question of the basis for design loads for assembly areas. The MEICON report asked respondents to estimate what the maximum load would be over the lifetime of a particular building. An alternative is to ask what maximum load should be considered for design in general. Perhaps this is a more realistic approach to setting the design loads for assembly areas, rather than extrapolating from surveys or collecting continuous data over long periods.

The MEICON project also created an office gathering space and populated it with differing concentrations of people. Shown below in Figures 1-5 are those results of the MEICON project that are germane to the current investigation. The project also considered additional loading conditions. These figures are results of their experiment (figures are used courtesy of MEICON, 2018).

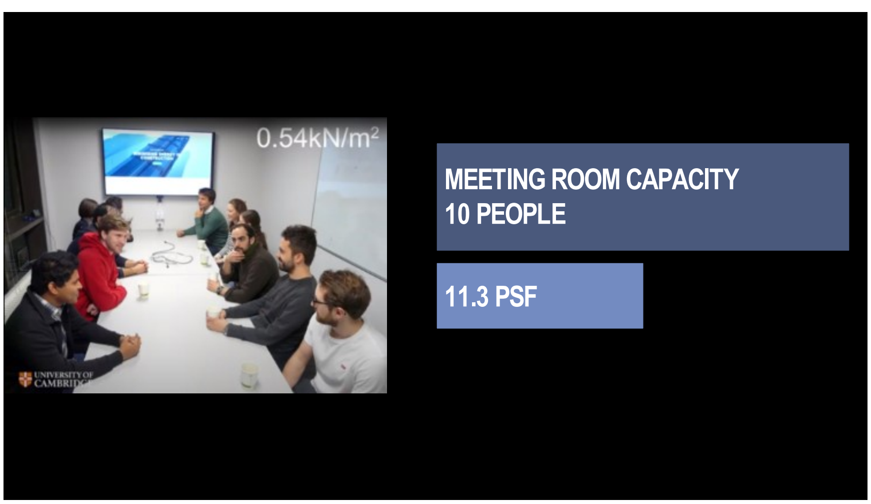

Figure 1. Live Load with Room at Capacity.

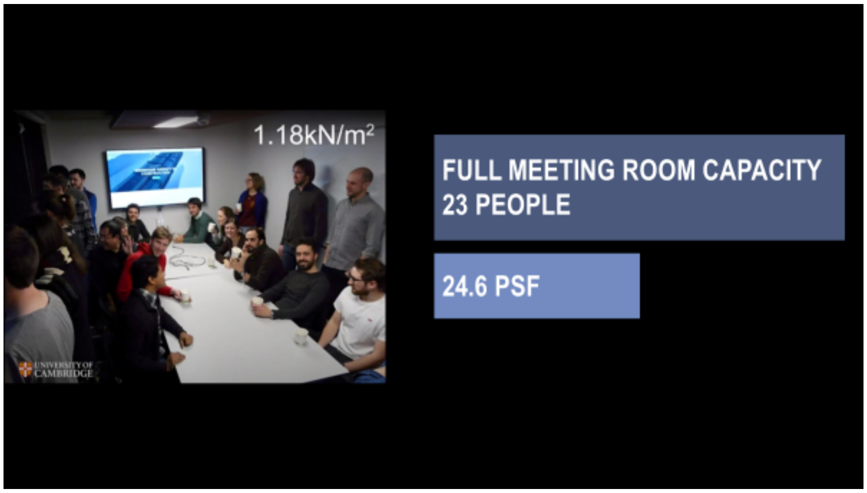

Figure 2. Live Load with Room at "Full Capacity".

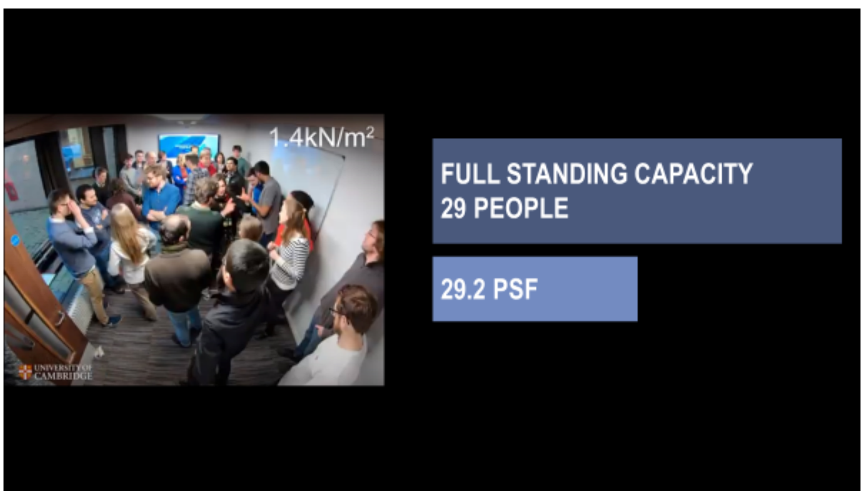

Figure 3. Live Load with Room at Full Standing Capacity.

Figure 4. Live Load with People Pushed into About 100 square feet.

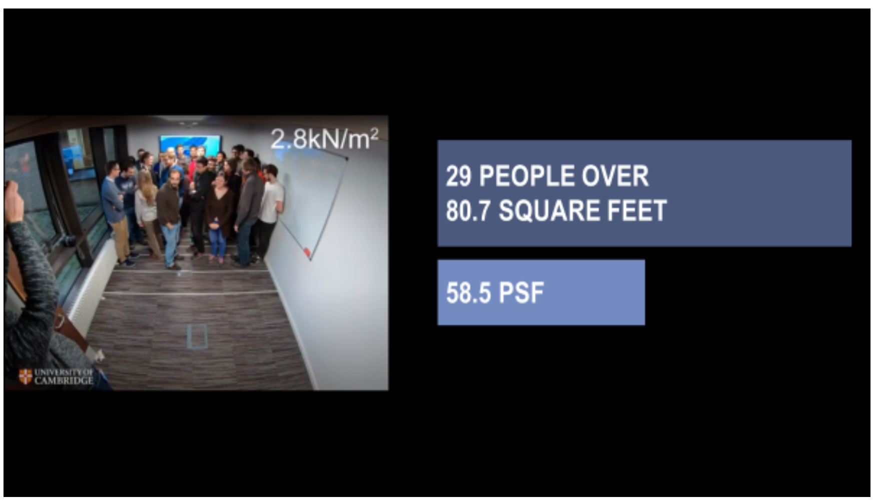

Figure 5. Live Load with People Pushed into About 80 Square Feet.

Golden Gate Bridge

On September 26, 2013, San Francisco held a celebration for the 50th anniversary of the opening of the Golden Gate Bridge. For that celebration, the city closed the bridge to traffic, allowing people to walk on the bridge. Figures 6 and 7 below are from a public website based on newspaper accounts on that day. These photographs provide a real-world experience of crowding over a large area. Crowding on San Francisco's Golden Gate Bridge for the 50 Year Celebration, produced a load of approximately 2.87 kN/m^2 (60 psf). This load estimate from MEICON [2018]. The load is based on the reported 300,000 people on the bridge (presumably at the same time), reported on page 63. From the photographs, one could consider that the observed loading of 2.87 kN/m^2 (60 psf) would be an upper limit for consideration of live load for assembly usage.

Figure 6. Crowding on San Francisco's Golden Gate Bridge for the 50-Year Celebration (September 26, 2013). Photograph from vintage.es: https://www.vintag.es/2013/09/pictures-of-golden-gate-bridge-50th.html, accessed January 5, 2023)

Figure 7. Crowding on San Francisco's Golden Gate Bridge for the 50-Year Celebration (September 26, 2013). Photograph from vintage.es: https://www.vintag.es/2013/09/pictures-of-golden-gate-bridge-50th.html, accessed January 5, 2023.

Borges and Castanheta – 1971

Borges and Castanheta [1971] did not conduct load surveys themselves, but they did run an experiment of crowding similar to that of Dunham, Brekke and Thompson [1952]. They used a 2 m by 2 m (6.56 ft by 6.56 ft) area set off with a structure similar to a guardrail. Their conclusion was that people could not move freely for loads above 1.96 kN/m^2 (41 psf). They also noted that loads of 3.93 kN/m^2 (82 psf) corresponded to "very compact crowds." Figure 8 is the figure from the Borges and Castanheta book, used by permission of the Laboratório Nacional de Engenharia Civil, LNEC [Borges and Castanheta, 1971].

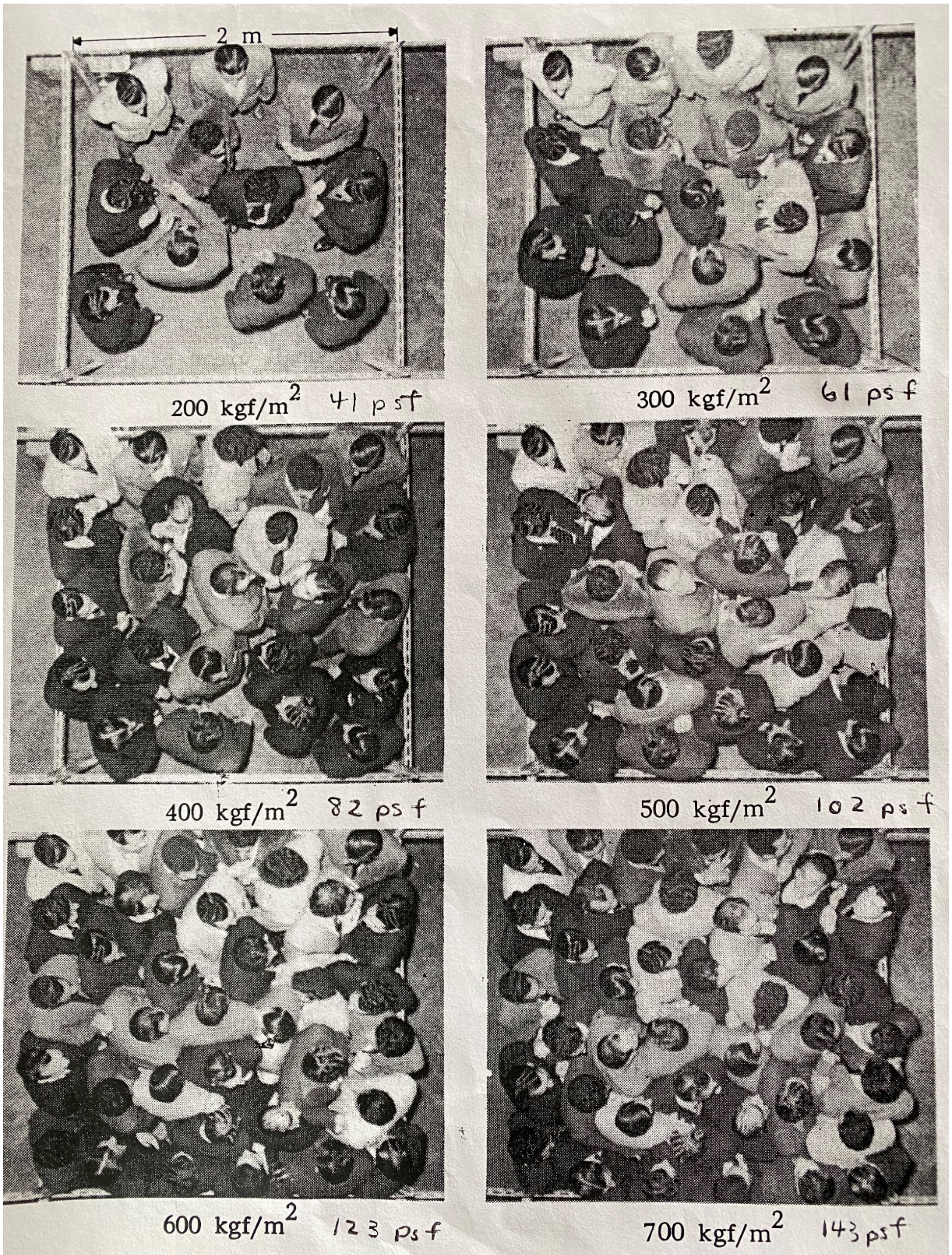

Figure 8. Crowding on a small area [used by permission, Borges and Castanheta, 1971].

5. A DIFFERENT APPROACH FOR GATHERING AREAS

Limitations of Existing Data

All of the surveys described in previous sections base their results on typical usage at the time of the survey, supplemented in some cases with estimates from the interviewees of their recollections or estimates of the largest crowds they could recall. The theoretical models base their estimates on this information, including stochastic modeling over the design life of a building. These surveys and models were extremely important for determining design loads for various occupancies, and for the calibrated concept of live load reduction. The transient loads due to people were appropriate for those occupancies.

However, these approaches are *not* appropriate for determining loads due to crowding that might occur in office gathering areas, particularly taking into account unusual situations, such as emergencies. Asking people to recall crowding for particular occupancy types such as offices and homes/apartments appears from their comments to generate recollections of gatherings such as parties and celebrations. These are of interest for the particular occupancies, but not for gathering areas in offices and their various roles.

The Growing Americans

It is important to note the change in average weight among Americans over the period of data collection. The early surveys by Blackall [1893] and the Department of Commerce [1923] both assumed an average person weighed 150 pounds (68 kilograms). Dunham [1947] and Dunham, Brekke and Thompson [1952] use this weight per person for business and mercantile occupancies, but in the second publication note for businesses that since "most of the occupants are females" that could have reduced this to 54 kilograms (120 pounds). For assembly, they assume a gender-weighted average of 59 kilograms (130 pounds) per person. For the 1971 survey of Mitchell and Woodgate [1971] in London, they noted that the average male weighed 71 kilograms (157 pounds) and the average female weighed 61 kilograms (134 pounds).

According to the U.S. National Center for Health Statistics [Department of Health and Human Services, 2021], the median (50 percentile) adult American male weighs 88 kilograms (193 pounds), and the median adult American female weighs 73 kilograms (161 pounds). This suggests an assumed weight for an unknown balance of genders should be close to 91 kilograms (180 pounds). On the other hand, one can reasonably assume that people are not getting denser or significantly taller. Over the past century, the average American male increased in height from 1.71 m (5'7") to 1.77 m (5'10"), while the average American female increased from 1.59 m (5'3") to 1.63 m (5'4") [see CNN access website in references]. These figures show a roughly 30% increase in weight and about a 3% increase in height. Therefore, these changes represent an increase in body mass index. One might assume that each person today occupies a larger floor area than 100 years ago, thus balancing to some extent the higher individual weight, but there is no definitive way to verify this. Fortunately, the calculations done in the MEICON study [2018] for their office experiments and the assessment of the Golden Gate Bridge celebration were based on current conditions.

Maximum Considered Live Load

It is appropriate to ascertain the maximum crowding load that could occur in gathering areas, which undoubtedly relate to unusual circumstances rarely occurring. Extrapolations from the types of questionnaires used in the past will not produce the requisite statistics associated with these situations. Instead, expert judgement focused on these particular situations will lead to their selection. Filtering out more typical events is analogous to the "peaks over threshold" mathematical approach for calibrating extreme events [Corotis and Dougherty, 2003; Dougherty et al, 2004].

The Delphi

Consistent with this logic, the authors implemented a different approach for office assembly or gathering space loads. A Delphi was performed with structural engineers from 31 of the leading design firms in the United States. A total of 36 firms were contacted, with selection based on their overall experience in structural design, their reputation in designing office buildings, and their participation in national organizations associated with building design (such as the Council on Tall Buildings and Urban Habitat, the National Council of Structural Engineers Association, etc.). In almost all cases the respondents were senior members of their firm with many years of experience. This was similar to the prior Delphi used to reaffirm and confirm occupancy live loads that appeared in ANSI A58.1 [1982], the forerunner of ASCE/SEI 7 [Corotis et al, 1981]. The Delphi method is a highly structured form of communication that seeks a consensus among a panel of experts, all of whom take part without attribution of individual responses to particular respondents. Achieving convergence usually results from a limited number of cycles, each of which circulates summarized responses back to the experts.

Each participant in the Delphi received background information, including a description of the potential situations leading to the load estimate sought. Also included were photographs from the Golden Gate Bridge celebration. Appendix A contains the Delphi document.

The goal of the Delphi was determination of the maximum considered assembly or gathering live load during a 50-year service life. Consistent with the other occupancy live loads in ASCE/SEI 7, the authors instructed participants to provide the expected (average, mean) office gathering live load that represented the maximum point-in-time value for consideration over the 50-year design life. As explained, this load would be part of the total live load for design. As such, it would be multiplied subsequently by the load factor associated with live loads in ASCE/SEI 7 (for instance 1.6 for most controlling gravity load combinations) [ASCE/SEI 7, 2022].

As mentioned, occupancy live loads in ASCE/SEI 7 correspond approximately to expected 50-year maximum values, consistent with the requested consideration of the Delphi participants. Reliability analysis for current loads incorporates the standard deviation for this lifetime maximum load, which typically is around 20%-25% of the expected value [Chalk and Corotis, 1980]. The reliability study that provided a probabilistic basis for design loads was National Bureau of Standards SP 577 [Ellingwood et al, 1980]. It used a coefficient of variation of 25%. A reliability analysis for the new approach for assembly or gathering space loads similarly necessitates an estimated standard deviation. The Delphi enabled estimates for the standard deviation by two methods, which will be discussed in the next section.

All responses from the first round of the Delphi were summarized (anonymously) and sent to the participants for their second-round responses. Convergence led to termination of the Delphi after two rounds.

Delphi Results

Responses to the first round of the Delphi were received from 31 leading structural engineers around the country. A list of those firms is provided in Appendix B.

Figures 9 and 10 show, respectively, the average and 90% levels of the fifty-year maximum load. Because of the high degree of agreement in this first cycle, it was decided for a second cycle just to ask respondents if they would like to alter their selection based on seeing these histograms. None responded.

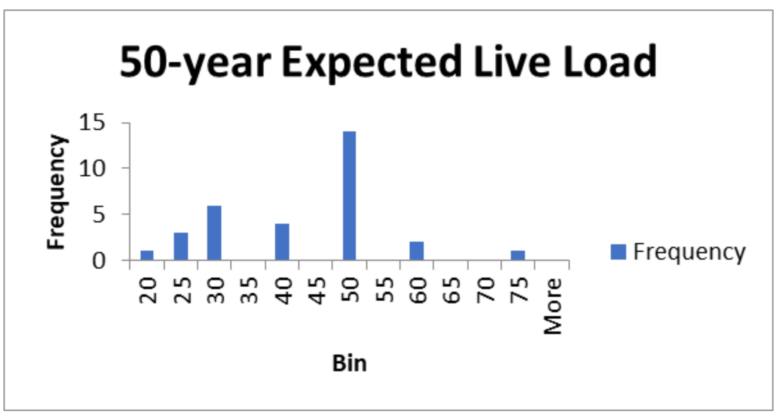

Figure 9. Reported Delphi Responses (in psf) for the Expected 50-Year Load.

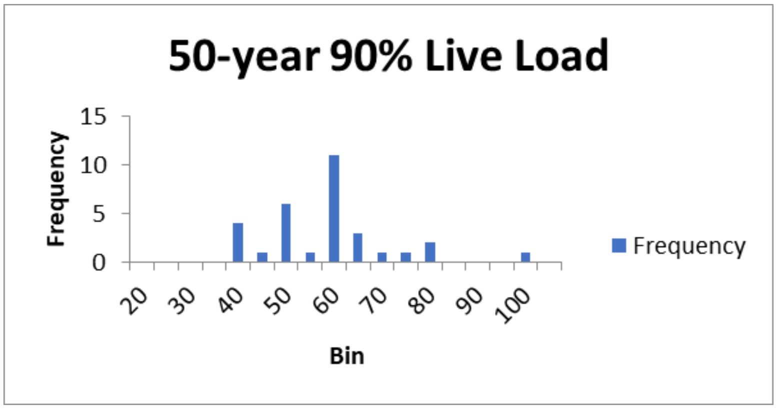

Figure 10. Reported Delphi Responses (in psf) for the 90% 50-Year Load.

There is clear consensus for an expected fifty-year maximum load of 2.39 kN/m^2 (50 psf). This is the strong mode and median, with almost half the votes there. Fewer than 10% of the respondents thought the value should be higher. Given reasonable projections, and the figures that were provided to the Delphi respondents, one could consider the responses of 0.96kN/m^2 (20 psf) and 3.59 kN/m^2 (75 psf) to be outliers, although that does not affect the conclusions.

There is also strong consensus for the 90% maximum load. Again, the mode and median are in agreement, 2.87 kN/m^2 (60 psf), which is also just about the average.

As mentioned previously, there are two methods that can be employed to compute the standard deviation. In one, the 31 responses for the 50-year expected live load are used to compute the standard deviation of those values. This method is a non-parametric calculation that measures the scatter in the responses. This is not considered the preferred method because it is actually measuring the variation of expert opinions on the average load, rather than the variability in the load itself. This calculation was performed just for interest, however, and it leads to a standard deviation around 0.57 kN/m^2 (12 psf). Again, it should be emphasized that this is the variation in the opinions of the experts on the 50-year expected load. The other method, considered more appropriate and robust, came from asking participants to supplement their estimate of the expected lifetime maximum value with a reasonable upper limit estimate; one with only a 10% chance that the design load (average maximum) should be this high. An assumed Type I Extreme Value form (Gumbel) was then used in a parametric method to compute the associated standard deviation Using this procedure with the results from the Delphi of a 50-year expected load of 2.39 kN/m^2 (50 psf) and a 50-year cumulative 90% load of 2,97 kN/m^2 (60 psf) yields a value of 0.37 kN/m^2 (7.67 psf) as the standard deviation of this expected 50-year maximum load. This corresponds to a coefficient of variation for the expected load around 10%. The standard deviation was also computed from each of the respondent's values individually (each of their 50-year expected and 50-year 90% value), and this led to a range of values, for which the most frequent was again 0.37 kN/m^2 (7.67 psf). It is noted that more than 90% of the values produced by this latter method yielded a coefficient of variation of 30% or less.

6. STOCHASTIC MAXIMUM LOAD ANALYSIS

While the Delphi results are quite conclusive, it was decided to also conduct a stochastic maximum load analysis consistent with the concepts in ASCE/SEI 7[2022], based on the work of Chalk and Corotis [1980]. The results of that analysis comprise Table C4.3-2 in the ASCE/SEI 7 Standard [2022]. The input variables for this analysis consist of the reference area, taken as 18.58 m^2 (200 ft^2), a reference period of 50 years, and a duration of sustained occupancy at 8 years, all the same as in the current ASCE/SEI 7 [2022]. One new value required is the expected intensity of a single transient load, taken as 0.54 kN/m^2 (11.3 psf), derived from the situation depicted in Figures 1 and A1, which was assumed to occur daily. Another is the standard deviation of that load, which was estimated from the variation between Figures 1 and 4, with assumed occurrence of Figure 4 being once in 50 years. Based on a gamma distribution (justified in the work of Chalk and Corotis [1980]), such a rare occurrence leads to a standard deviation of 0.29 kN/m^2 (6.0 psf). The only other statistics required are the mean and standard deviation of the sustained load. As is clear form Figures 1 and A1, space for gatherings should not be assumed to be the same as the usual office furniture. As a matter of fact, they are more akin to those often found in school classrooms. From the judgement of the authors, and a load survey conducted by the first author, the mean value for the sustained load was estimated at 0.14 kN/m^2 (3 psf), with a standard deviation of half that, since it is expected to rarely exceed 0.24 kN/m^2 (5 psf). It is noted that this is less than the office sustained load given in Table C4.3-2 of ASCE/SEI 7 [2022]. The difference is that the personnel load is being treated separately here as a transient load, whereas the value in ASCE/SEI 7 includes personnel normally present.

The stochastic load analysis was conducted by Professor Sanjay Arwade of the University of Massachusetts Amherst, and his Postdoctoral Fellow Adem Karasu and Associate Professor Kara Peterman, who had implemented the Chalk and Corotis algorithm for a new study they were conducting on roof live loads. This used the Chalk and Corotis [1980] algorithm, reprogrammed by the colleagues at the University of Massachusetts Amherst. This led to a fifty-year expected value of 54.1 psf (2.59 kN/m^2 (54.1 psf). This is close to and slightly less that the value of 2.63 kN/m^2 (55 psf) that currently appears in ASCE/SEI 7[2002] based on the underlying stochastic load analysis for offices. Given the uncertainties associated with the assumptions, it is concluded that the stochastic analysis is consistent with the Delphi.

7. RECOMMENDATIONS

Based on the responses to the Delphi and the stochastic maximum load analysis, the authors are suggesting that as a clarification to designers and code officials, a new entry be included as a sub-category under the *Office buildings* heading in the ASCE/SEI 7 Live Load Table 4.3-1. A suggested title is *Office meeting, gathering, and collaborative work spaces*. Similar to the other occupancies, one should specify the design load as the expected 50-year maximum load. Examination of the crowding situations observed leads one to conclude that it would be very difficult to exceed 2.87 kN/m^2 (60 psf) over any area other than a very small one.

For floors that are not directly accessible from outside and not intended to be used by the general public the crowding will come from unusual, but predictable situations, such as special group meetings or holiday gatherings. In this case, comfort dictates that the load should not exceed 2.39 kN/m^2 (50 psf), well below the 2.87 kN/m^2 (60 psf) observed on the Golden Gate Bridge. Alternatively, crowding could come from the movement of people from adjacent areas due to emergency circumstances. In this case, the availability of personnel from surrounding areas will provide a natural limit, and even over a 50-year period, one would expect that the load would not exceed 2.39 kN/m^2 (50 psf). A load of 2.87 kN/m^2 (60 psf) could be considered as an upper limit with only about a 10% chance of exceedance. One can expect the crowding in the latter case to be the more severe of the two scenarios. In these situations, the natural limit from surrounding areas (and adjacent floors in the case of refuge areas) provides a reasonable control, and for structural elements supporting a floor, a value of 2.39 kN/m^2 (50 psf) is proposed.

The current ASCE/SEI 7 office load was based partially on the theoretical model of Chalk and Corotis [1980]. This combined a sustained load with an extraordinary load process, the latter representing crowding of people. That model assumed a load cell area of 6.9 m^2 (74 ft^2) with an average of four people per load cell. Such crowding in offices was assumed to occur once per year. The theoretical model led to a 50-year maximum expected extraordinary load of 1.76 kN/m^2 (36.7 psf), which was then combined with the sustained load to produce a lifetime expected maximum load of 2.63 kN/m^2 (55 psf). From these calculations, the code committee selected a design load of 2.39 kN/m^2 (50 psf). Since the current study for office gathering spaces has led to a recommendation of 2.39 kN/m^2 (50 psf) *total* load during extreme office gatherings, there is no need to combine this with any pure sustained load or with another extraordinary load of crowding. For comparison purposes, however, the same procedure that was used in the Chalk and Corotis [1980] study was applied to support these new findings.

This recommended level for floors that are not directly accessible from the outside is consistent with the results from the Delphi. As explained above, the recommended value for the standard deviation of the 50-year maximum load is 0.37 kN/m^2 (7.67 psf). This coefficient of variation around 15% is about two-thirds to three-quarters of the 50-year load for other occupancies [Chalk and Corotis, 1980; Ellingwood et al, 1980], therefore leading to a somewhat higher level of reliability. This standard deviation produces a coefficient of variation that is about three-quarters of the 20% used for office loads in the current ASCE/SEI 7 standard.

For floors directly accessible from outside (including their associated balconies and mezzanines), it is recommended that the assembly load remain at the current value of 4.79 kN/m^2 (100 psf), which is consistent with most current specifications for lobbies and first floor corridors.

With a recommended design load for office gathering spaces of 2.39 kN/m^2 (50 psf), the question of live load reduction immediately arises. The concept behind reduction is that large areas are not likely to be simultaneously loaded to the full design load, which is based on the 50-year expected maximum [Chalk and Corotis, 1980]. For office gathering spaces, one needs to consider that these gatherings are likely to occur quite frequently, as opposed to the relatively rare crowding situations that are the basis for the current ASCE/SEI 7 office design load. But it is deemed extremely unlikely that the full design load would occur over multiple locations at the same time. And the people crowding into a gathering space would normally be coming from other adjacent floor areas, thus supporting the use of live load reduction. Indeed, most such gatherings are expected to look more like what is shown in Figure 1, at the most. Therefore, there is nothing from the current study that would support any difference from the current live load reduction concept and formula.

8. CONCLUSIONS

This review of available data, the theoretical analyses and the Delphi all indicate that the design load for office gathering spaces should be taken as the same as offices in general, at 2.39 kN/m^2 (50 psf). The Delphi, the examination of crowding situations and the stochastic maximum load analysis all indicate that this does not compromise the code's ability to protect building occupants. In addition, live load reduction should be permitted for these spaces, just as it is for offices in general, with a consideration of a maximum reduction of 50% for structural elements supporting one floor, and 60% for those supporting two or more floors. For office gathering areas on floors directly accessible from the outside, the current code requirements should be maintained, as described in the previous section..

Since embedded energy is highly dependent on the total mass of material used in construction [Hendrickson et al, 2006; Junnila and Horvath, 2003; Cabeza et al, 2014], these guidelines should result in significant savings in comparison to designing all floor levels as assembly areas at 4.79 kN/m^2 (100 psf), and without live load reduction.

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9. DATA AVAILABILITY

Some or all data, models, or code used during the study were provided by a third party. Direct requests for these materials may be made to the provider as indicated in the Acknowledgements.

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APPENDIX A

Delphi Document

Appended below is the actual document that was sent out to the Delphi participants. The only change below is that in order to save space in this paper, all photographs have been omitted here except one because the others were the same as those appearing in this paper. The omitted figures are Figures 1-7 in this paper.

September 2022

Dear Structural Designer:

In collaboration with Magnusson Klemencic Associates and the ASCE Subcommittee on Dead and Live Loads, and with the sponsorship of the Charles Pankow Foundation, your firm has been selected as one of our country's leading structural engineering designers to take part in this brief but important survey. Your response is requested on the questions listed below. This survey is part of a Delphi investigating the possibility of expanding the live load provisions in the ASCE/SEI 7 Standard to explicitly address office assembly areas. In recent years, interior office designs have included a variety of gathering, training and collaborative work spaces that many Authorities Having Jurisdiction have deemed to be "assembly spaces". This determination requires that structural engineers apply a 100 psf non-reducible live load when designing the floor system.

This Delphi study is similar to the one conducted about 50 years ago to update and reaffirm live loads for use in codes and standards. The Delphi method is a highly structured form of communication that seeks a consensus among a panel of experts, all of whom take part without attribution of individual responses to particular respondents. We will report back to you a summary of responses, requesting additional responses if another cycle is warranted.

Live loads occurring during unusual crowding are challenging to predict, and are inherently different from the everyday sustained loads, which can be reliably gathered from point-in-time field surveys. Those typically represent the portion of the live load that is normally present for the intended function of the area. It should be noted that the current office live load requirement of 50 psf does reflect such crowding considerations, since the typical sustained load is around 11 psf. If you are interested in a more detailed explanation of the development of live loads, see the ASCE/SEI 7-22 Commentary to Chapter 4, particularly Table C4.3-2, and the references cited there. Areas in which people regularly assemble are likely to have a live load with a large sustained portion, but not necessarily transient.

We are seeking to define an expected maximum considered Office Assembly live load, which should represent the maximum live load expected in the office collaborative area (we note that expected values are slightly different from "most likely" or "median" values, but you may think in terms of the latter two if you are more comfortable with these concepts since the difference for the extreme distributions used is not large). This new concept is intended to include any areas within an office building in which a large number of people might regularly gather, and the question of whether the standard office occupancy load might be considered inadequate for these collaborative areas. As with other occupancy loads, these represent the expected maximum value the area will see over its 50-year design lifetime. In a probabilistic sense, these expected values are the mean (average) values of the 50-year maximum. This is different from a probability of failure since load and resistance factors are subsequently applied.

The objective is not to determine the maximum total (sustained plus extraordinary) live load that crowding can physically cause, but rather the <u>expected</u> maximum an office assembly area will see over a 50-year period. Please note that office assembly areas are areas that are intended for the building occupants, not for the general public; typically, these areas would <u>not</u> include the first floor and associated balconies/mezzanines.

We are providing a few figures in order to offer some perspective in terms of actual crowding of people. These are merely to give some sense of regular assembly loading as well as crowding (and the Golden Gate Bridge photographs may help to visualize what 60 psf looks like).

YOUR RESPONSES

Your estimate of the <u>expected</u> largest office assembly area live load <u>for consideration</u> in design:

_________________psf

Your upper value estimate such that you think there is only a 10% chance the office assembly design live load should be this high:

_________________psf

Figure A1. Typical usage of collaboration space for an office.

APPENDIX B

Engineering and Design Firms of the Respondents to the Delphi

BASE

Buro Happold

Cary Kopczynski & Company

DCI Engineers

Degenkolb Engineers

DeSimone Consulting Engineers

Englekirk Structural Engineers

Forefront Structural Engineers

Forell/Elsseser Engineers, Inc.

Gilsanz Murray Steficek LLP

Holmes Consulting Group Inc.

KPFF Consulting Engineers

LeMessurier

LERA Consulting Structural Engineers

Martin/Martin, Inc.

McNamara Salvia Structural Engineers

Magnusson Klemencic Associates, Inc.

Nabih Youssef & Associates

Odeh Engineers, Inc.

PCS Structural Solutions

886 Raths, Raths & Johnson, Inc.

887 Saiful Bouquet Structural Engineers

888 Simpson Gumpertz &Heger

889 Silman, A TYLin Company

890 Skidmore Owings & Merrill

891 Stanley D. Lindsey and Associates, Ltd.

892 The Harman Group, now IMEG

893 Thornton Tomasetti Inc.

894 Uzun + Case

895 Walter P Moore

896 WSP USA