WIND INDUCED CREAKING NOISE IN TALL BUILDINGS – PART 1

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ABSTRACT

During the last decade increasing numbers of high-rise apartment residents have reported disturbance from creaking noises seemingly generated within the building structure during high winds. It is a growing phenomenon as cities continue to build upwards, yet due to the sensitivity of the topic, it is seldom openly discussed. Building on experience studying the topic in a consultancy capacity, this research aims to address some of the key knowledge gaps, namely: identification of the mechanism generating the creaking; control measures that target the mechanism; and how the noise can be assessed to determine the relative magnitude of impact. Data from extended noise monitoring in affected rooms during a range of wind speed conditions, paired with targeted vibration measurements on various internal fit-out building elements have been used to study this issue. Findings to date demonstrate that the noise is generated when a building sways laterally due to wind loading. This leads to inter-storey drift causing rigidly fixed internal fit-out elements to rub against one another as they overcome static friction (or stiction). This releases energy which is manifested as noise when reradiated by connected elements. In steel frame wall constructions, this is found to primarily occur along the interface between the head track and studs. Mitigation therefore relies on mechanically decoupling the offending elements, whilst maintaining structural stability and safety. The paper will report on modifications which can achieve the necessary decoupling, and a methodology to assess the relative impact of the noise in modified and unmodified constructions.

1 INTRODUCTION

Owing to the sensitivity of the topic, published research on wind-induced creaking noise is limited beyond the anecdotal sail-boat analogies published in popular media,[1] and as such, a significant knowledge deficit exists in the acoustics industry regarding the systems that cause the phenomenon and what can be done to mitigate it. This ongoing PhD research project therefore aims to assist acousticians in assessing the sound by focusing on four primary research directives, namely:

1) identifying the mechanisms that contribute to the sound;
2) developing a methodology to measure and assess the sound;
3) benchmarking existing mitigative systems and contributing to the development of a new system; and
4) developing a risk assessment that can be used during design stages to identify if a building may exhibit the sound.

This paper focuses on identifying the mechanisms that contribute to the sound, the outcomes of early development of a measurement and assessment methodology and some high-level insight into mitigative efforts that can limit the occurrence of the sound.

2 MEASUREMENTS & MECHANISMS

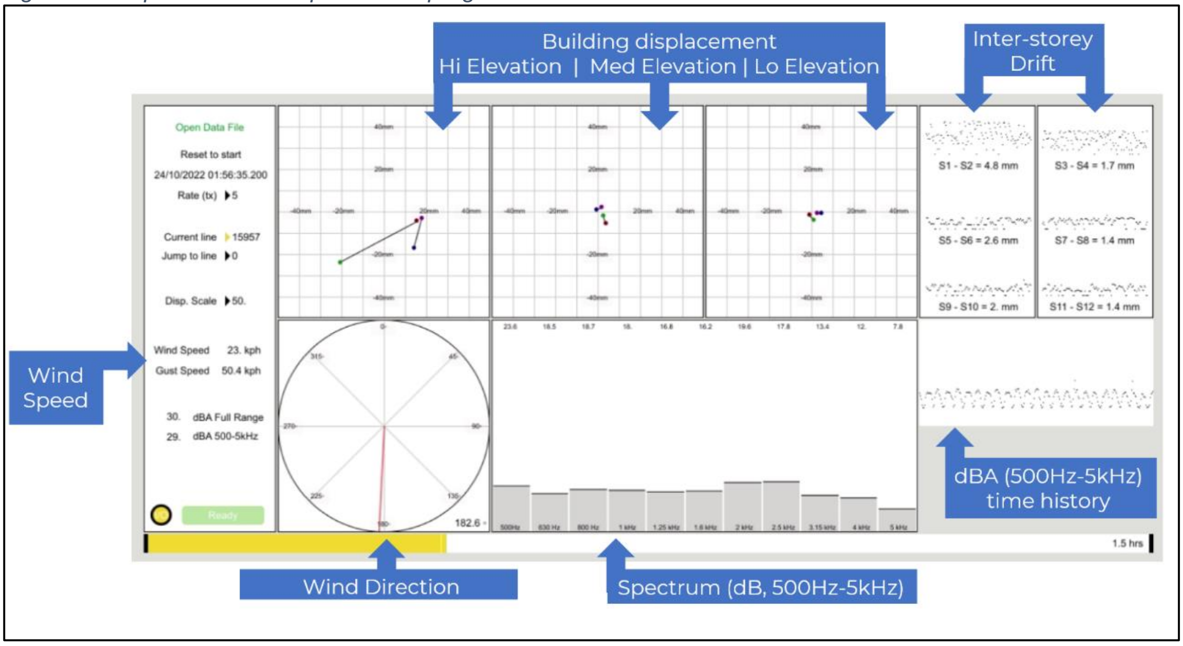
As for many acousticians professionally involved in the topic, the journey into this research began with a client enquiry regarding an uncommon sound within a tall building. The author, on behalf of Clarke Saunders Acoustics, visited the site to observe the sound as well as to conduct some early investigative measurements. These pilot studies included some attended noise monitoring within an affected building, paired with vibration measurements along various internal fit out elements within a wall. Vibration measurements along the various elements quickly gravitated to the boundaries between the studs and head-track as the data suggested that the epicentre of the sound was at these connections.

Unattended noise measurements within affected areas of the building were then undertaken alongside wind measurements on the roof of the building, at a height of +10m. A careful review of the noise data exposed a clear character and pattern of the sound in both the time and frequency domains, which has been confirmed as part of long-term monitoring in a number of buildings exhibiting the creaking sound. In the frequency domain, the sound is typically limited between the 500Hz and 5kHz third-octave bands with varying dominant frequencies, typically around the 1kHz and 2kHz octave bands. In the time domain, the sound often varies in duration, with individual creaks often lasting between 1 and 2 seconds repeating rhythmically during peak wind conditions.

This identification enabled a detailed analysis of noise and wind data. A review of the wind data showed that average wind speeds were not sufficient in identifying all creaking periods as these are typically measured in 10-minute durations as per BS EN IEC 61400-50-1:2022,[2] whereas 3-second gust speeds provided a clearer relationship with the creaking sound. The time histories of the datasets showed a good correlation (between 0.5 and 0.7) between the noise and wind data which made clear that the noise is indeed occurring during periods of sustained, increased wind speeds.

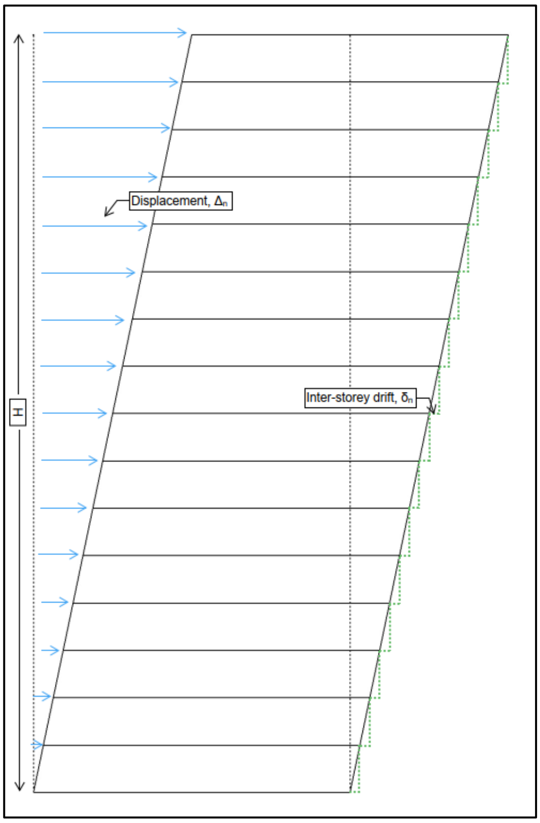
A study of building displacement was then undertaken on a building which exhibited the sound. This featured a number of triaxial transducers placed at varying elevations of the building all monitoring movement at a time interval of 100ms. Noise was also measured at a rate of 100ms during periods of increased wind speeds. Due to the size of the dataset that was collected during these periods, a bespoke programme to analyse the data was required. A system was developed in the programming language Max.MSP to organise and visualise the data. An annotated still image of the system is presented in Figure 1.

Figure 1: Bespoke noise / displacement programme



The results of the study demonstrated that the noise occurs during periods of significant, sustained wind loading where higher levels of displacement were exhibited. As the building is loaded, the building displaces, often non-linearly across the elevation,[3] which is formed by individual storeys moving at slightly varying levels to one another: a phenomenon referred to as inter-storey drift that imposes floor-by-floor forces on the lightweight fitout elements. The general relationship between displacement and inter-storey drift is illustrated in Figure 2.

Figure 2: relationship between displacement and inter-storey drift



Through close observation on affected sites as well as research undertaken as part of the FIS Tall Buildings Working Group,[4] it was found that as the individual storeys displace relative to one another, internal fit out elements can be strained, particularly those that are friction fit. The significant lateral loading that can occur during these periods causes the elements to overcome static friction (or stiction) and release energy in incremental steps, which is manifested as vibration within the system, ultimately translated as reradiated sound, that can be described as “creaking.”

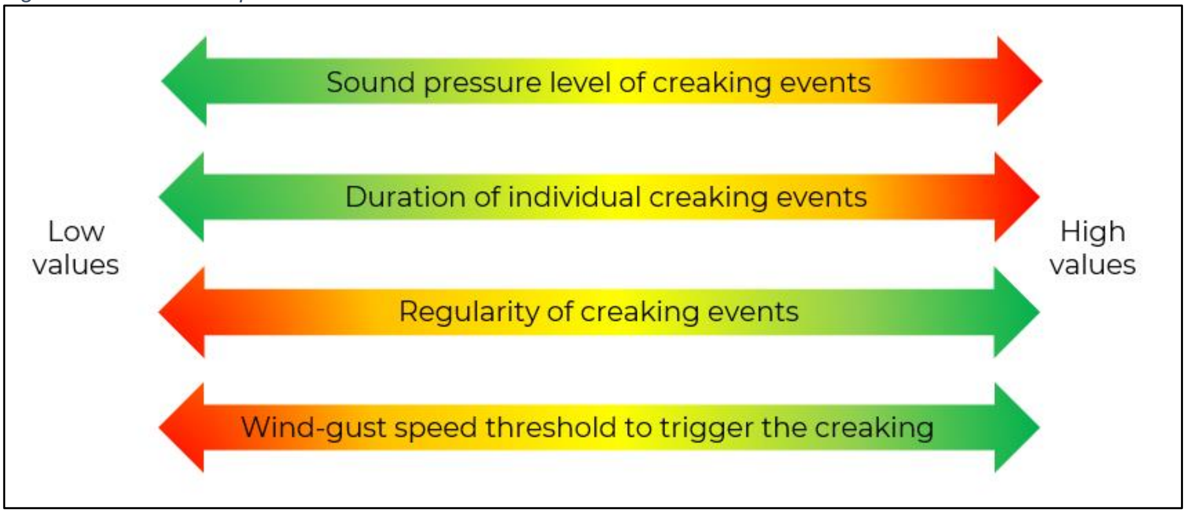
It should be noted at this stage that this form of building movement is not only common, but an essential component to structural stability and safety.[3]

The displacement study further demonstrated that the relationship between internal noise levels and local displacement is not linear (i.e. increasing displacement levels did not translate into increasing sound pressure levels beyond a maximum threshold). It was thus concluded that the situation represents a system with a fixed saturation point in which there is a maximum level of energy that can be produced by the internal connections within the constraints of a building scenario. However, during periods of particularly high loading, more studs can be energised, resulting in a “chorus” of creaking sound. This emphasized the need for an assessment that considers other dimensions of the sound to better categorise impact.

3 ASSESSMENT METHODOLOGY

Given the distinctive character of the sound, a number of parameters were identified which could help contextualise potential impact including 1) the objective sound pressure level of the creaking, 2) the duration of individual creaking events, 3) the regularity of the creaking events, and 4) the wind-gust speed threshold which is required to trigger the creaking when exceeded for sustained periods. These elements are illustrated in Figure 3 along with relative implications of higher and lower values for each, with red relating to higher indication of impact and green relating to lower indication of impact.

Figure 3: Assessment parameters



It should be noted that the parameters described in Figure 3 are not tied to any specific numerical values due to the variability in conditions between buildings. It was found that one assessment model would not necessarily be applicable to other buildings, as this has the potential to be misinterpreted when determining the relative implications of impact. Instead, the system was found to be suitable for comparisons between retrofit modifications within a specific building to their previous unmodified state in order to help objectively categorise improvements onsite, post-intervention.

The primary effects of the noise relate to annoyance and sleep disturbance. A reasonable parameter to consider for objective noise levels would therefore be a value related to L_{AFmax}. However, it was found that a statistical analysis is more effectively applied to a statistically derived measurement parameter and therefore use of a statistical parameters such as L_{AF01} was experimented with and was helpful in some scenarios where the dataset is more highly affected by sporadic, erroneous, non-creaking events.

During the studies it was found that the duration of individual creaking events could play a large role in assessing impact. An event that is short in duration can be less noticeable than one that is drawn out over several seconds.

Inversely, the regularity (or return period from one stud activation to the onset of another) of an event would be highly noticeable if regularly occurring every several seconds or so, when compared to a sound that only occurs once a day, once a week or even more rarely which could even go unnoticed by a casual observer.

With regard to the wind-gust speed threshold, the lower the threshold value is, the more regularly occurring the sound may be, as opposed to a relatively high threshold that may only be exceeded over a strictly limited period throughout the course of a year.

Although derived subjectively from observation and self-reported impacts, these parameters have shown to capture the factors influencing human response to the phenomenon enabling us to link this back to the physical mechanisms at work..

3.1 Complications & Applications

A significant complication in the assessments undertaken as part of this research is isolating creaking sound from non-creaking sound. Other sounds present within a tall building during windy conditions can share similar characteristics to creaking, most significantly, sound from wind buffeting on the facade of the building.

The calculation model developed as part of this research is focused on identifying the objective characteristics of the sound considering both time and frequency domains. The model assumes that the sound would be clearly audible over the background by calculating a background sound level derived as the lowest 10th percentile of rolling 10-second periods. The model also assumes that the sound will range between 500Hz and 5kHz with dominant frequencies often (though not exclusively) ranging between the 1kHz and 2kHz octave band regions.

The model is then calibrated for each space and period to exclude erroneous, lower level, non-creaking sound. This is done by accounting for the differential between the existing background and the level of creaking sound. The third-octave spectrum (between the identified frequency range) is then reported for each potential creak identified by the model. The spectrum is derived as the maximum value per third octave band over the duration of the identified creaking event. For each identified event, the duration and start time reference is recorded to allow for a calculation of duration and regularity.

With this information, a schedule of creaking event spectra along with duration and regularity statistics can be generated. Given the variability in sound types present in a typical unoccupied flat, particularly during periods of adverse weather, the data is analysed to identify creaking events from non-creaking events. However, given the large dataset, some uncertainty remained, likely including sound levels from wind buffering that exceeded the creaking noise in level. It was also found that one single value to represent each of the assessment parameters is insufficient in categorising the creaking sound, but rather the resulting dataset needed to be presented in its entirety to demonstrate the variability of the parameters. Use of histograms for each of the parameters was investigated as part of the research and in the early trials of the assessment methodology appeared to be helpful to communicate the outcomes.

4 MITIGATION

The primary mechanism generating the sound has been identified as friction fit internal wall elements that overcome static friction under significant wind loading conditions. Over the course of this research two primary streams of mitigation strategies have been observed: 1) structural modification in the form of tuned mass or sloshing dampers, and 2) modification of the stud to head track connection.

The research into mitigation is still ongoing, though some initial guiding principles have been identified.

With structural modification systems in the form of structural damping, the maximum amplitude of the building movement can be significantly reduced, though it should be noted that the primary function of these systems is not to target creaking effects but rather to improve structural stability and motion comfort within a building. The details of objective studies into the systems must remain purely anecdotal at this stage owing to sensitivities of the research specimens, however it was found that when implemented appropriately in certain building constructions, the effects of the creaking can be reduced. Mass and sloshing dampers require careful consideration early on in the design stages of a development due to the financial and spatial cost required to accommodate such a system, and as such, these are not suitable for retrofit mitigative efforts. Emerging technology may serve to change this in the future, with the development of the *Hummingbird* damping system providing opportunities to apply a more distributed damping solution better suited to retrofit, [5] though it is understood that the system is in the early stages of project trials.

Stud modification, however, comes in several forms. Some of these come in the form of proprietary, commercially available products such as Studco[6] and Stud Connector (previously known as Motion Frame),[7] among others; and others in the form of non-standard builders work methods. All of the systems rely on the same principle, namely mechanically decoupling the stud from the headtrack. It has been observed that these systems are becoming more commonplace in new constructions and retrofits alike with some installations bearing higher 'success' than others. The challenge with the stud modification strategy is that these systems are only effective in the studs that are modified, with one unmodified stud within a space serving to potentially compromise the perceived efficacy of the entire intervention.

5 CONCLUSIONS

Wind induced creaking noise in tall buildings is a growing phenomenon as more tall, slender buildings emerge. Due to the high sensitivities surrounding the topic, published research is limited, and rarer still is the guidance for formal acoustic assessments. Advancements are being made as part of this ongoing PhD research project to aid in the assessment of the noise and communication of relative severity.

The mechanism contributing to the noise has been identified primarily as friction-fit internal wall elements that overcome static friction under significant wind loading conditions. The state of mitigation efforts currently falls under two general strategies: structural modification and stud connection modification, with early observations indicating that both have the potential to reduce the occurrence of the noise when appropriately adopted.

6 REFERENCES

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