Building Economics of Wind-Engineered Tall Structures – Part 2: Construction Cost and Returns on Investment

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Abstract: This two parts paper investigates the impact and value of wind engineering for a common tall building shape. In Part 1 of the study, details and methodology of high-frequency force balance (HFFB) tests were presented and empirical formulae were proposed to define the relationship between wind-induced loads and responses and the effects of introducing corner modifications to the building shape. In Part 2 of this paper, the empirical formulae proposed in Part 1 are employed to estimate the construction cost of a tall building project. The rental income for an office building was also used to demonstrate the process by which optimal building dimensions may be determined to maximize financial profits.

1.0 INTRODUCTION

Buildings are expensive. The decision to enter into the real estate market usually involves the largest single-item expenditure that most people have to deal with during their lifetime, even if they are merely renting an apartment. Expressed in terms of income, the cost of a flat is generally several times the annual salary of an individual wage earner. Spread out over time as monthly mortgage payments, it can require anywhere from a quarter to one-half of the monthly family income [1].

For a developer and/or other investors in a tall building project, the initial financial outlays and burden generally provide a compelling motivation to sell, lease or rent as soon as possible after their completion. It is obviously desirable to maximize the profit, by way of maximizing the difference between their investment and the sale prices the buyers are willing to pay, and to realize that profit as soon as possible.

The economic issues for buildings are definitely a major concern for the building developer. It is not prudent to ignore a concern which the client often considers to be the most critical one, even if concerns of others facets, such as structural safety and project schedule, are more important to an engineer or project manager. Including economic factors in our range of design concerns will not compromise our designs; it will make us better engineers.

2.0 WIND TUNNEL TESTS & RESULTS

A series of wind tunnel high-frequency force balance (HFFB) tests for buildings with different modified corners was conducted at the CLP Power Wind/Wave Tunnel Facility, The Hong Kong University of Science and Technology. The building models under investigation were variations of a reference building, having a basic square plan shape. Different sizes of corner modification were sequentially introduced to the reference building and additional storeys were added to compensate for losses in floor area. Measurements were taken at 22.5° increments for 90°, starting from the incident wind angle normal to the building face and power spectral densities (PSDs) of the dynamic components of the measured base moments were obtained. The details and methodology employed for the HFFB tests was presented in Part 1 of this study.

The PSDs of the dynamic components of the measured base moments were used in conjunction with representative dynamic properties (mass distribution, natural frequency, damping and mode shape) to evaluate analytically the prototype scale cross-wind dynamic responses. It was assumed that the fundamental natural frequency of the building is inversely proportional to the building height (50/H), building mass is uniformly distributed, mode shapes are linear and uncoupled, and the structural damping ratio was set to be 2% of critical. The maximum cross-wind response of all measured wind directions was determined and then separated into background and resonant components and are shown in Figure 1.

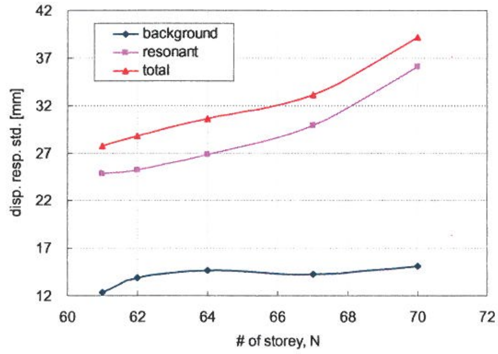

Figure 1. Cross-wind responses of corner-modified buildings

To understand the combined effect of corner modifications and additional storeys with regard to the financial returns, empirical formulae were derived in Part 1 to relate the cross-wind background dynamic response and resonant dynamic response to the number of storeys which are basically interrelated with the construction cost. The formulae are also depicted in Figure 1 and details were presented in Part 1.

3.0 CONSTRUCTION COSTS

The initial costs associated with a tall building project would typically include the land cost, development costs (such as clearing the site and providing access), professional fees (for architects, engineers, lawyers etc), fees for permits, equipment costs, and construction costs [2,3], among others. In Hong Kong, for example, the land cost dominates the initial cost and the construction cost may not even make up half of the total initial cost [3,4]. Nevertheless, it is the largest single cost item and, from the engineer's perspective, the cost that is most directly related to and influenced by their design decisions. It is quite obvious then that this aspect deserves the attention of skilled professionals to achieve functional engineering solutions that satisfy the necessary safety and performance objectives within the framework of achieving desirable cost reductions.

There are a variety of methods currently available for estimating the costs of building projects. For example: the whole unit method, area method, volume method, enclosure method, systems method, trade breakdown method. Some of these methods may have discrepancies as high as 50% depending on supplied information and the different stages during the construction process [5,6]. On inspection, the systems method seems to be comparatively precise and suitable for construction cost estimation [7]. According to the systems method, a building is considered to consist of various subsystems according to their main function, such as the foundation, floor system, superstructure, roofing, exterior wall system, HVAC, electrical etc. The focus of this study is on the construction cost of the superstructure as it constitutes over a one-fifth of the total construction cost and they are dependent on the building responses and hence the wind loads.

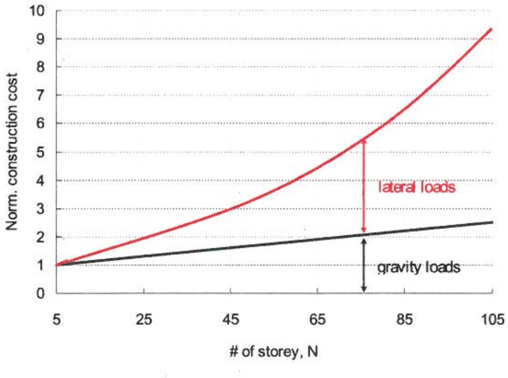

Figure 2. Normalized construction cost of tall buildings

The construction cost of a building is broken up into fractions according to those resisting gravity loads or lateral loads [8] and those cost fractions are shown in Figure 2 with respect to the number of storeys (N). The cost to resist gravity loads increases linearly with increasing height as the gravity load is proportional to the total weight of a building. The cost to resist lateral loads increases nonlinearly with height as the overturning moment due to wind loads varies quadratically with respect to N and exceeds the gravity load component from around 60 storeys onward.

In this study, the buildings under investigation range from 60 to 70 storeys, and therefore their construction costs are likely to be governed by the wind loads. The introduction of corner modifications reduces the wind loads and hence the construction cost. However, the addition of compensatory storeys to maintain floor area increases the wind loads and the construction cost. The combined effect of modified corners and additional storeys on construction cost is estimated based on the empirical formulae derived in Part 1. They are then normalized by the construction cost of the reference building and are illustrated in Figure 3.

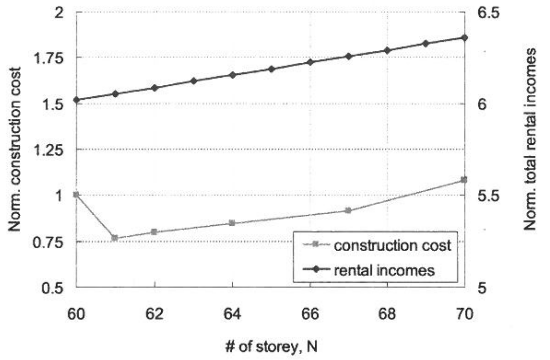

Figure 3. Normalized construction cost and rental incomes of wind-engineered tall buildings

4.0 RETURNS ON INVESTMENT

The construction costs are always a major concern for professionals, their reduction may dominate design decisions in actual tall building projects. However, these costs are only part of the overall economic performance of a development and to focus exclusively on these may even be counterproductive. A more balanced approach is to relate the costs to the values or benefits received in return for the investments.

There are several basic and distinct forms in which economic rewards can be obtained from building projects [9]. The first is the economic value of using the building for the owner/investor's own operations, for example as a company's own headquarters. In that case, the benefit is entirely intangible and indirect. Secondly, the building can be sold to another party and the freehold tenancy is transferred to the new owner in return for the proceeds of the sale. The third possibility is that of leasing or renting the whole or parts of the building to others, in return for periodic payments. For the second and third options, the economic benefit is entirely monetary and focused on the profits, that is the money received from the sale proceeds or rental incomes over and above the cost the seller originally invested in the project. The primary focus of the current study is to evaluate the economic performance of a fully rented commercial building.

In estimating income from leases and rentals from a building, the proper interpretation of market information is essential and a reliable prediction can be obtained only from thorough analyses and knowledge of the market conditions prevailing in the area where the building is located. In most developed countries, there are government departments, organizations, or associations collecting the rental rates and sale prices on the market according to different locations and the information can be readily obtained on request. Therefore, reliable and up-to-date market rental rates are generally available for different locations.

Although rents are normally paid monthly, for the purpose of estimating their economic value they were calculated as annual payments in the current study. Given the established annual rent from a reliable source for year 0 (RT_0), the annual rent for a future year n (RT_n) will be [9]:

$$RT_n = RT_0(1+f)^n \qquad (1)$$

assuming that rentals increase annually at a fixed rate of inflation (f). Considering vacancies and bad debt losses as an amalgamated quantity (VR_n), the nett rental income (NRT_n) would be:

$$NRT_n = RT_n(1-VR_n) \qquad (2)$$

It sometimes takes a considerable amount of time before reaching the expected stable occupancy level in large multi-tenant projects. Therefore, the income projections should consider higher vacancy rates during the "lease-up" period; for example, 40% during the first year, 20% during the second year, and approaching the stable state of 10% in the third year after completion. In this study this arrangement was used and the total rental period was assumed to be 20 years.

Elevation of an apartment or office is also an important factor influencing the rental rates. Some data sources may have already made distinctions for elevation within a building type, and others offer additional adjustment factors to be applied to the general market rates for that location. It is advantageous in this study to use an equation in which the elevation factor appears as a variable. For example, the effect of elevation can be expressed as an exponential function as follows:

$$RT_m = RT_1(1+r_h)^m \qquad (3)$$

where RT_m is the rent for an office at floor m, and r_h is an adjustment coefficient which is the rate at which the rent rises with respect to the number of storeys. This rent rise rate needs to be established from a given set of data.

For the sake of comparison, the nett rental income over 20 years is also illustrated in Figure 3 as a ratio to the construction cost of the reference building with respect to the number of storeys. The maximum profit (i.e. difference between the rental income and construction cost) was found to occur at a building height of 67 storeys.

5.0 CONCLUDING REMARKS

The influence of corner modifications and increasing building height on the construction cost of the structural system and foundation of a tall building was determined based on the empirical formulae derived in Part 1 that relate the cross-wind background dynamic response and resonant dynamic response (dependent on the type and size of corner modification) to the number of storeys. General speaking, the construction cost was reduced with the introduction of recessed corners even though the building height increased. The monetary rewards, i.e. rental income, of a building were also discussed.

As this study is currently in its preliminary stages, it is recognized by the authors that only a very small portion of overall building economics has been explored. Evidently, the benefit of using the building for the owner/investor's own operations is entirely intangible and indirect, and this has not yet been examined in detail in this study. The problem of such intangible benefits, like the functional, emotional, and aesthetic user needs, is that they are difficult to connect with an economic value in a direct quantitative fashion that can be expressed in a mathematical formula. This leads to an understandable but problematic tendency to give more weight to those factors that can be dealt with in a quantitative manner, with the potential consequence of ignoring or undervaluing other quality aspects. However, it seems to be difficult to achieve a promising means to balance the tangibles and intangibles when it must compete with mathematical formula. Much work remains to be done on this issue.

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