# Towards Sustainable Development Through Innovative Engineering

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## INTRODUCTION

In 1999 the total number of Public Housing units constructed in Hong Kong was 53,000, while in the private sector some 33,500 completions were reported, giving a total number of residential units in all sectors of 86,500 (Hong Kong Housing Authority, 2001). The construction materials used in for the structure of these apartments are almost exclusively concrete and steel in the form of reinforcement. If a 10% reduction in the use of these materials could be made, this would equate to the structural component of 8650 units, or around 25 residential towers. If one considers that construction today is a waste disposal problem for the future it is worth putting this volume of material into perspective. In 1999 approximately 40% (8000 tonnes per day) of all material disposed of in Hong Kong's Strategic Landfill Sites was Construction and Demolition (C & D) waste. The majority of C & D waste sent to the Strategic Land Fill sites was non-inert material, while 29,000 tonnes of inert C & D waste (mostly slurry and material arising from excavation) was required for Public Fill Areas such as Tsuen Kwan O (Waste Facilities Bureau, 2001). It is indicated that demand for public fill will diminish significantly over the coming years as reclamation is scaled down. The total volume of structural material contained in 25 no. 35 storey residential buildings is in the order of 700,000 tonnes, which represents around 24% of the quantity of C & D waste disposed of in Strategic Land Fill sites in 1999. Therefore, initiatives that reduce the amount of construction material stored in current housing stock are important in addressing the problem of future waste disposal.

This paper will demonstrate that through the adoption of innovative structural engineering principles designers can play a major role in reducing the pressure on both natural resource supply and waste assimilation capacity of Hong Kong's environment.

## CONCEPTS OF SUSTAINABILITY

### Ecological Modernisation

Ecological modernisation describes how certain industries are responding to environmental concerns through a reorientation of their existing methods and working practices. Innovation and technology are able to expose new markets for more environmentally responsible products and services. The transition of the Hong Kong Taxi fleet to LPG by 2005 is an example of this trend. An essential ingredient of ecological modernisation is the appropriate intervention of national governments to provide the necessary momentum for innovation to flourish.

The construction industry in Hong Kong is beginning this process of industrial change. This is evident in the many initiatives that have emerged from within both private and public sectors, over the last 5 years. Within the public sector, the Planning Department's SUSDEV 21 study and the Construction Industry Review Committee's Construct for Excellence report have emerged. In the private sector, developers are voluntarily committing to HK-BEAM assessments, contractors are exploring the use of cleaner more efficient construction systems, and engineers look for solutions that make more efficient use of natural resources. Government initiatives such as the 1st Joint Practice Note on Green and Innovative Buildings and the recently awarded Hong Kong Housing Authority architectural competition, “Public Housing in the New Era”, are raising awareness and adding momentum to the concept of sustainable development.

## Framework for Sustainable Development

The following definition of sustainable development is taken from the SUSDEV 21 study:

*“Sustainable Development in Hong Kong balances social, economic, environmental and resource needs, both for present and future generations, simultaneously achieving a vibrant economy, social progress and a high quality environment, locally, nationally and internationally, through the efforts of the community and the Government”*, (SUSDEV 21, 1997).

This definition encompasses five core ideas. These are summarised in the following framework adapted from Jacobs (1997):

| | | |
|---|---|---|
| ***Quality of life*** | - | a recognition that the well-being of Hong Kong’s citizens is a function of the quality of the built environment |
| ***Efficiency*** | - | a commitment to the efficient use of all resources (including environmental ones) |
| ***Environmental protection/Ecological limits*** | - | a commitment to protecting natural resources and amenities and to living within the limits created by the ‘carrying capacity’ of the environment |
| ***Equity*** | - | a commitment to meeting at least the basic needs of present and future generations |
| ***Participation*** | - | a recognition that there are many different stakeholders whose values should be considered in the design, construction and implementation process of development |

The challenge for engineering professionals is to consider this sustainability framework in the context contact of current practice in the construction industry. The structural engineer can play key roles in the following areas:

- Structural design should balance material cost with the value of the space being occupied by the structure.

- The structural engineer is responsible for specifying economic design and should seek to make the most efficient and appropriate use of structural materials.

- The structural engineer has a commitment to continued research and development, thereby growing the knowledge base for both current and future generations.

- It is important that the structural engineer understands the contribution of all stakeholders in the development process. Of particular emphasis in this respect is the recognition of the role of the contractor and placing a strong emphasis on construction led design.

## ENGINEERING SUSTAINABILITY

Structural optimisation is an essential process in the design of building structures. The concept is not new, as structural engineers have traditionally sought to make the most efficient use of structural materials. In Hong Kong there are two area, where advances in engineering technology are allowing significant benefits to be realised: computer aided structural optimisation and wind engineering. The flow chart in Figure 1 illustrates the basic set of procedures that form the structural optimisation process.

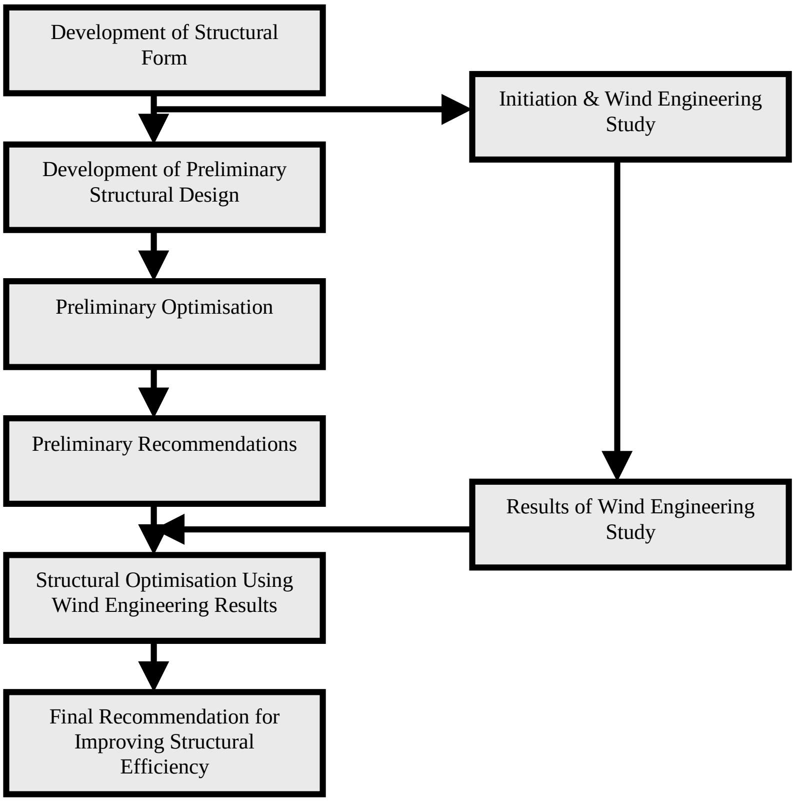

Figure 1 – Structural Optimisation Flow Chart

### Computer Aided Structural Optimisation

Unlike conventional trial-and-error design methods, computer aided structural optimisation is a goal-oriented design synthesis approach that seeks the optimal design analytically, while satisfying all specified design criteria. In such an analytical optimisation approach one needs to first define explicitly the optimisation objective and design constraints in terms of design variables and then develop an appropriate optimisation algorithm for solution. This approach has been used successfully on a number of building structures in Hong Kong and is currently being used on the proposed Home Ownership Scheme, Public Housing Development in Shui Chuen O, Sha Tin. The project is a site-specific residential development promoted by the Hong Kong Housing Authority and comprises 7 tower blocks varying in height from 32 to 38 storeys. The tower blocks are positioned in three groups (or clusters). Two of the clusters

Figure 2 – Artist's Impression of Shui Chuen O Development

comprise 3 linked towers, while one cluster is a single stand-alone tower. Figure 2 shows an artist's impression of the development.

The optimisation which has been performed on the Shui Chuen O project has targeted the following parameters:

(i) minimum structural material cost
(ii) maximum usable floor area

In this case, only the construction cost of the lateral system and the value of usable floor area have been considered. However, it is worth noting that other costs associated with engineering, social, economic, political, and environmental issues over the life span of the building could be incorporated if these cost functions were to be explicitly defined.

The optimisation techniques described in this paper are based on advanced algorithms. Further details of the optimisation methodology can be found in Chan (2001) and Chan et al. (1998).

## Preliminary Optimisation

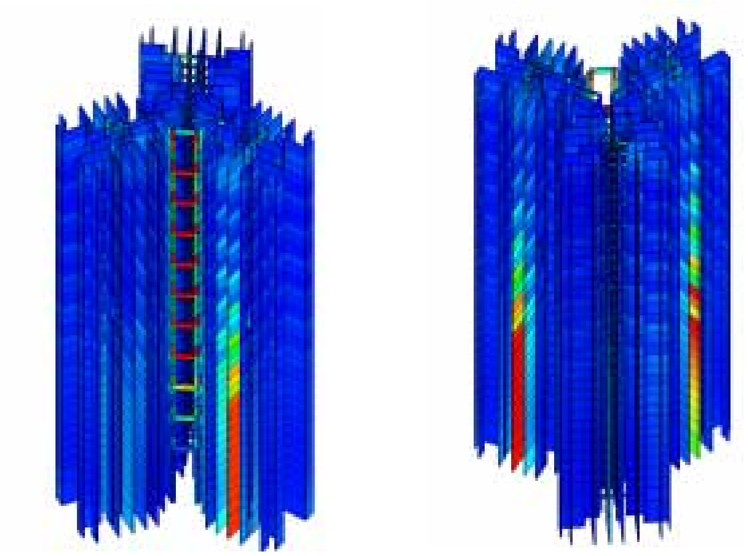

Figure 3 – Identification of Efficient Elements

Preliminary optimisation has been carried out for a single block of the development based on analytical and empirical estimations of wind loads. The procedure uses computer aided structural optimisation technology to determine the work efficiency of each structural element. The relative work efficiency of each element is explicitly determined in terms of percentage strain energy densities. Figure 3 presents graphically the relative cost efficiency of structural elements of a single tower of the Shui Chuen O development. The hotter colours represent elements of higher efficiency, whereas the cooler darker colours represent the less efficient elements.

Optimisation allows structural material to be redistributed to those elements that make the greatest contribution to the overall stiffness of the building. The more efficient elements are increased in size while the less efficient elements are downsized such that the cost efficiency of the structure is improved while maintaining the structural performance of the building. The scale of redistribution can be set within parametric limits based on the minimum required dimensions for strength and the maximum practical size from aesthetic and spatial considerations.

On the basis of the preliminary optimisation, recommendations were made to adjust various structural walls, lintels and tie beams. The results of this are presented in Table 1 below.

Table 1

| | Before Optimisation | After Optimisation |
|---|---|---|
| **Vol. of concrete per CFA ($m^3/m^2$)** | 0.349 | 0.307 |
| **Area of walls per CFA ($m^2/m^2$)** | 0.114 | 0.107 |

- Percentage savings in concrete = 12% of the concrete volume of the lateral system
- Increase in Usable Floor Area (UFA) = 1% of Construction Floor Area (CFA)

## Wind Engineering

Wind engineering in Hong Kong is a complex issue, and if not correctly addressed during design can lead to either over-design or under-design. These situations generally occur when a designer does not appreciate the limitations of the Hong Kong Code of Practice on Wind Effects (1983), particularly with respect to tall, exposed and unusually shaped buildings. These limitations are noted in the opening paragraph of the Code, but are often overlooked by users. Over-design is most common in the prediction of structural loads, although this often results from the very conservative wind speeds in the Code, while under-design using the Code can often occur in the prediction of local cladding loads. Neither under-design nor over-design are concepts consistent with the ideals of sustainability: over-design results in a wastage of materials while under-design may result in damage to building contents if, for example, windows fail during typhoons. The wind engineering approach to the sustainable structural design of buildings in Hong Kong can be illustrated with reference to the Shui Chuen O project.

### *Design wind speeds*

Buildings Department require the use of a 64 m/s mean hourly wind speed at gradient height for a nominal 50 year return period. It is generally recognised that this wind speed represents a much longer return period, although there is a great deal of disagreement between researchers about the correct value of 50 year wind speed. The gradient height (the height at which wind speed reaches a maximum) is defined by BD as being 200 m in general terrain. However, this height is modified significantly by terrain, as are the local wind characteristics of wind speed and turbulence intensity at building heights. Both need to be modelled correctly in order to accurately predict the wind loads. As the effects of terrain are cumulative over a long distance, local wind characteristics must be investigated using a small-scale model at typically 1:2000 to 1:4000 scale. The model used for Shui Chuen O is shown in Figure 4.

As is often the case, mean wind speeds for the most common easterly wind directions were found to be lower at building height than those implied by PNAP 150, but gust speeds were higher, as a result of the steep topography increasing turbulence levels. It is important to consider both mean and gust wind speeds to accurately predict wind loads on buildings.

### *Prediction of structural loads*

Structural wind loads on buildings must be measured at larger scale, typically between 1:300 and 1:500 although even larger scales may be used in special circumstances. There are a number of methods of determining structural loads e.g. aeroelastic modelling, high-frequency force balance testing, high-frequency pressure integration. The most efficient method for public housing works is normally the high-frequency force balance (HFFB) technique. This is a rigid model technique that allows ready re-analysis of the aerodynamic data during the design process to account for design development of the structural system. Where there are multiple blocks with structural linkage or linked to a common podium, multiple HFFBs need to be employed simultaneously in order to achieve an efficient design. In the case of Shui Chuen O, three force balances were used simultaneously under each of the clusters. One of the Shui Chuen O models mounted in the wind tunnel surround model is shown in Figure 5. The surround model contains a high level of local topographic detail to allow accurate simulation of flow interactions around the development. The profiles above this model were calibrated to match those measured above the topographic model.

The peak base moments measured in the wind tunnel were around 70 to 80% of those that would have been predicted by using (inappropriately) the Hong Kong Wind Code. The outputs from the Shui Chuen O multiple HFFBs were analysed simultaneously to develop load combinations that work to provide maximum stresses in each structural element under at least one load case. This resulted in a total of 83 load combinations for each of the 3-tower clusters and 24 load combinations for the strand-alone tower. In-house software was used to batch-run the structural analysis software with these load combinations. These wind engineering approaches allowed a very efficient design to be undertaken, with subsequent environmental and economic benefits.

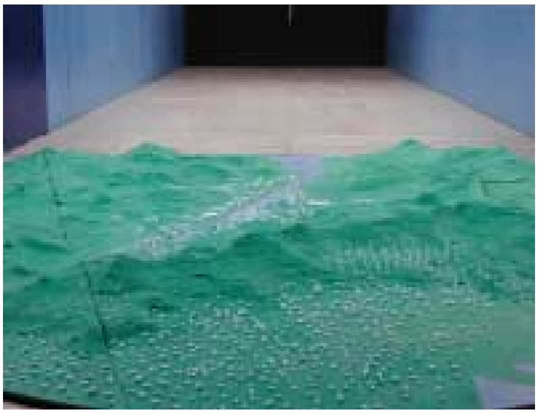

Figure 4 – 1:3000 Topographical Model

Figure 5 – 1:400 Scale Test Model

### Detailed Optimization

Following completion of the wind engineering study, a detailed optimisation was carried out for the entire Shui Chuen O development. The loadings used in this detailed optimisation were those derived from the wind tunnel test. Minimum element strength sizes were established on the basis of more the accurate loads and these formed the minimum size bounds for the detailed phase of the structural optimisation study. All of the 83 wind load combinations were considered in this detailed optimisation study.

A summary of the savings in structural material and the benefits resulting from increases in usable floor area are presented in Table 2.

Table 2

| | Preliminary Design | Stage 1 Optimisation | Stage 2 Optimisation |
|---|---|---|---|
| **Vol. Of concrete per CFA ($m^3/m^2$)** | 0.349 | 0.307 | 0.283 |
| **Area of walls per CFA ($m^2/m^2$)** | 0.144 | 0.107 | 0.093 |

- Percentage savings in concrete = 19% of the concrete volume of the lateral system
- Increase in UFA = 2.1% of CFA

This detailed optimisation process has been conducted for all 7 residential tower blocks with the result that, from preliminary design to post-detailed optimisation, around 6500 $m^3$ of concrete have been saved in the lateral load resisting elements. The saving in concrete volume in percentage terms (including the concrete in the floors, which are not optimised with lateral stability system) is around 10% of the total volume of concrete in the domestic blocks of the development.

While it is understood that savings in concrete volume could be realised through a process of trial error, the unique combination of computer aided structural optimisation and specialist wind engineering skills provides a more systematic approach to maximising the available benefits.

## DESIGN MANAGEMENT

It has been shown how the adoption of innovative computer aided structural optimisation and wind engineering techniques can have significant benefits in terms of material use in building structures. It is important, however, to recognise and understand the contribution of other stakeholders in the overall design, construction, and implementation process of development. The Hong Kong Housing Authority has recently established the Premier League of Contractors as a means of both encouraging and recognising consistently good working practices. The project team responsible for the design of the Shui Chuen O development has encouraged the involvement and constructive input of the Premier League Contractors and other stakeholders in the design process. This involvement has been facilitated through various workshops.

Before commencement of the scheme design, representatives of Housing Authority (senior management, maintenance and facilities management representatives, project managers, and consultants) and the Premier League Contractors were able to exchange ideas and concerns in a Value Management Workshop. The recommendations of this workshop were carried through to scheme design stage. Prior to the completion of the scheme design stage a series of Focus Forums were held involving the Housing Authority project management team, the consultant team and the Premier League Contractors. These meetings were held specifically to address the construction-led design concept. The knowledge that was shared at the Focus Forums was disseminated at a Value Engineering Workshop, again attended by the major stakeholders, which enabled the consolidation of the scheme design.

A further initiative has involved the establishment of close dialogue with the Housing Authority Quality Task Force. A series of working meetings have been held to review issues relating to durability and maintainability of the Shui Chuen O development. This initiative has proved effective in informing the design team of the concerns of those stakeholders responsible for the future maintenance of the finished buildings.

## CONCLUSIONS

It has been demonstrated that innovative engineering techniques such as computer aided structural optimisation and wind engineering have an important role to play in the move toward sustainable development. By using these techniques, designers are able to make significant reductions in the volume of structural material used in Hong Kong's Buildings.

The sustainability framework presented in this paper provides a set of guiding principles for the continued development of sustainability-driven innovation in engineering. The final section of this paper emphasises that innovation should be incorporated into development in a rational manner that recognises the importance of other design and performance issues. A move toward sustainable development requires that the concerns of all relevant project stakeholders are recognised and understood.

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