A3.1 Conceptual Designs to Resist Hurricanes

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1 Conceptual Design

1.1 The Need for an Integrated Approach

Conceptual design involves a series of decisions among which are:

(1) the geometry or shape or configuration of the building (OHPT[1]-1&2);

(2) the siting of the building (OHPT-3&4);

(3) the materials of construction;

(4) the structural system (OHPT-5,6,7).

So basic are these issues that they must be addressed at the earliest stages in the development of a project. All parties should be involved at this stage - client, architect, engineers, constructors. The present organisation of the building industry makes it difficult for constructors to be involved in design development. This is a pity. However, this places a greater obligation on architects and engineers to understand the construction process better, to understand the implications of their design decisions on costs and facility of construction. Costs are affected by relative ease of construction; availability of materials, equipment and labour; time for construction. In some societies the responsibility for monitoring costs is given to a separate discipline - the quantity surveyor. It would be better if the knowledge of costs resided in the minds of the designers. To take this argument to its logical conclusion, it would be better if one person (the conceptual designer) had facility in architecture, engineering, cost estimating and construction. Such a person used to be the Master Builder.

> *"Civilization is built on Specialisation. Specialisation may destroy Civilization."*
> *Arup*

1.2 Total Design Chronology

When engineers become involved in "design", they take out their calculators too quickly. True design precedes detailed calculation. To be sure, some calculation is required in the process of

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[1] Overhead projector transparency

design, but the principal calculations can only be done after the bulk of the design has been done. Mathematics is then a tool for refining the design and for determining the details of construction. This is not to downplay the importance of structural analysis and detailing. It is to emphasise the proper chronology of these functions. The life cycle is as follows:

(1) Design (*ie* conceptual design)

(2) Analysis

(3) Detailing

(4) Construction

(5) Maintenance

(6) Demolition

Each function is affected by each other stage in the cycle, but this is not at variance with the order of precedence given above. Good analysis cannot make up completely for bad design, and good construction can certainly not correct bad detailing.

2 Non-engineered Buildings

Structural configuration is the single most important factor in determining the performance of buildings subjected to hurricanes. The following recommendations are proposed and are particularly appropriate for **non-engineered** construction and for **minimum cost** construction:

(1) Limit height of buildings to one and two storeys.

(2) Ensure that lightweight floors and roofs are securely fastened to the walls to improve their performance in hurricanes.

(3) The shape of the building should be, as far as possible, symmetrical. This symmetry also applies to the arrangement of partitions and openings. This would lead to a more balanced distribution of forces in the structure.

(4) Provide sufficient distance between openings to avoid slender piers. Keep the openings moderate in width to avoid long-span lintels. (OHPT-8)

(5) Link the heads of all walls together by providing a continuous collar or ring beam at floor and roof levels.

(6) Lightweight roofs should be not less steep than 20 degrees (generally speaking, the steeper the better up to about 30 degrees) to improve their wind resistance.

(7) To improve their wind resistance lightweight roofs should have a hipped shape (sloping in four directions) rather than a gable shape (sloping in two directions) or a monopitch shape. (OHPT-9)

(8) Again, to improve their wind resistance, lightweight roofs should have minimum overhangs at the eaves. In fact is would be better to have no overhangs and to introduce a parapet. The need to shade windows and doors from sun and rain may be met by separate canopies. (OHPT-10)

(9) The incorporation of ridge ventilators would reduce internal pressures and therefore help in keeping on lightweight roofs in a hurricane.

Clearly, the above recommendations are very restrictive indeed. But to vary significantly from them would require the conscious involvement of engineers to achieve safe construction. Today's technology permits almost anything to be done. In fact, it could be said that advances in technology are responsible for much bad design. Technology (and money) permits badly designed buildings to be made safe. The aim is not to restrict design but to sensitise people to those factors requiring caution.

3 Other Characteristics of Wind-resistant Design

Heavy structures resist winds better. But sheer weight alone is not sufficient for success.

Flexible structures attract greater wind forces. Typically, buildings with a natural period greater than 1 second warrant special treatment. In general this would apply to buildings over 10 storeys or buildings with a height-to-width ration greater than 6.

Hurricanes are usually regarded as imposing horizontal[2] loads on buildings. However, the vertical loading derived from wind is usually significant on parts of a building as determined by aerodynamic considerations. Indeed, most damage done by hurricanes is due to loads which are closer to the vertical than the horizontal. These are the roof uplift loads. Wind loads act normal to the affected surface. The exception to this with conventional buildings is the frictional forces parallel to the affected surface. This can be important with very long buildings. Professor Davenport[3] has often said that a good test for a wind-resistant building is to turn it upside down and shake it.

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[2] In the USA the phrase “lateral loads” is used in describing both wind and earthquake loads.

[3] Alan G Davenport, Chairman, Boundary Layer Wind Tunnel Laboratory, University of Western Ontario

So the effective design and construction of buildings to resist hurricanes would correspond to the following tenets:

- Symmetrical shapes are favourable
- Compact shapes are favourable
- The designer must realise that there is a real risk that "design" forces may be exceeded. This leads to a requirement for redundancy in the structure and for "toughness" - the ability to absorb overloads without collapse.
- Connections are of paramount importance. Each critical element must be firmly connected to the adjacent elements.

The performance expectations in the event of a hurricane are that the building is expected to survive its "design hurricane" with virtually no damage. Even a catastrophic hurricane should only lead to repairable damage.

The source of loading is mainly external, due to wind pressures. The type of loading is fluctuating, but predominantly in one direction. The duration of loading is usually several hours.

There is usually good predictability of loads by extrapolation from records or by analysis of site and wind patterns.

Local soil conditions do not significantly influence the building response.

The main factors affecting building response are external shape and size of building. Dynamic properties are unimportant except for very slender structures.

The normal design basis is for the maximum credible event and elastic response is usually required.

The design of non-structural elements is confined to external cladding.

4 The Antigua Experience in 1995

As an example of importance of conceptual design on the safety of buildings in hurricanes, here is an excerpt from my report on Luis in Antigua[4]:

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[4] Effects of Hurricane Luis (September 1995) on Structures in Antigua by Tony Gibbs for presentation at The Second Caribbean Conference on Natural Hazards and Disasters Jamaica, 09-11 October 1996

"....... The analyses of causes of failures indicate quite clearly how most of the failures could have been reduced to manageable amounts and, in many cases, eliminated completely with little incremental effort and cost.

"Damage to buildings was mainly due to weak connections of light-weight roofing and siding materials, impact damage to glazed openings from flying objects, inadequate fixings of windows and external doors and water damage from the torrential rains. There were also examples of catastrophic collapse of entire buildings due to unsound structural concepts. The lack of maintenance of building components contributed significantly to the damage. .... The actual wind speeds were not greater than should have been expected in a 1-in-50-year event. The introduction of mandatory building standards and codes would have a significant, positive impact in reducing losses in future hurricanes."

"Conceptual Design

"This is the single most-important factor determining success or failure of buildings. Once again this was demonstrated during Hurricane Luis in Antigua. With respect to hurricanes, suitable design concepts are particularly important for light-weight structures - timber and corrugated-metal walls and roofs.

"Unfavourable features evident in Antigua were:

- ***L**-shaped plans;*
- *mono-pitched roofs;*
- *shallow-pitched gable roofs;*
- *long overhangs at the eaves and gables;*
- *long overhangs continuous with the main roof;*
- *corner balconies.*

"Favourable features evident in Antigua were:

- *compact plans;*
- *hipped roofs;*
- *steep-pitched gable roofs;*
- *short overhangs at the eaves;*
- *canopies discontinuous with the main roof;*
- *parapets"*

"Non-structural Elements and Issues

"Windows and external doors are the orphans of the construction industry and their acts of revenge for lack of attention can be very embarrassing. Usually engineers are not involved in the specification of these items. Usually architects are not equipped to determine the strength requirements for these items. Usually suppliers and contractors cannot be relied on to provide more than the commercial norm, which is inadequate for .... many situations .... There were several failures to be seen, which is not surprising. The failures were sometimes of the fixings to the walls. At other times glass was broken by flying objects. The only ways to deal with vulnerability to breakage are the installation of hurricane shutters and the use of laminated glass. The latter approach would still lead to breakage but the weather would be excluded during the hurricane."

5 The Cost of Mitigating Damage

5.1 Case I - Favourable Concepts

For the single-storey and two-storey buildings the cost of making the favourably-shaped ones virtually invulnerable to future Category-4 hurricanes would be a maximum of 3% in initial capital cost (based on exercises carried out by the author, and others, on similar facilities). Most of this incremental cost would be used in protecting windows and external doors and securing the lightweight roofing and siding.

5.2 Case II - Unfavourable Concepts

Where the buildings are of unfavourable shape the cost of virtual invulnerability to Category-4 hurricanes could rise to a maximum of 7.5% in initial capital cost. This incremental cost would be used, not only in protecting windows and external doors, but also in adding strength to the entire building envelope because of the higher wind forces generated by the unfavourable shapes.

5.3 The Cost of Controlling the Building Industry

Standards and Codes - In the overall context of the construction industry in general and critical facilities in particular, the cost of preparing standards and mandating codes is negligible.

Checking and Monitoring - If these functions are to be carried out effectively for design as well as for construction, an additional, one-off cost of 1% to 2% of the original construction sum is an average estimate. Spread over the (say) 50-year life of a building this figure becomes infinitesimally small.

Regulating the Professionals - This cost is almost zero. Several Caribbean countries already have in place a Registration of Engineers Act. The registering of engineers and the monitoring of the profession is, in those places, covered by annual registration fees paid by the said professionals. This would amount to no more than a few thousands of dollars, nothing that can be quantified as a measurable percentage of construction costs.

A3.2 Conceptual Design to Resist Earthquakes

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1 Configuration

Buildings are designed by architects and engineers. In reality, in most cases, buildings principally for human occupancy are designed conceptually by architects. That is to say that architects are the ones principally responsible for the configuration of buildings for human occupancy.

Configuration has to do with the shape and size of the building. Inevitably shape and size to a large extent determines (or greatly influences) the type, shape, arrangement, size, location and most other aspects of the structural concept. Also, the architectural configuration determines the location and nature of non-structural elements of the building.

The extended definition of "configuration" therefore encompasses:

- architectural shape and size;
- type, size and location of structural elements;
- type, size and location of non-structural elements.

In the words of Geoffrey Wood[5]:

> *"Earthquake-resistant design is really a problem for architects."*

The architect determines the conceptual design of the building and in so doing largely determines the type and effectiveness of the earthquake-resisting systems which can be used by the structural engineer. Because of this, it is of paramount importance that the architect have a better-than-usual knowledge of the basic principles of the conceptual design of earthquake resisting systems. Alternatively, the architect should involve the structural engineer in the initial discussions and development of the building concept.

The Tri-services Manual of the USA Army, Navy and Air Force states:

> *"A great deal of a building's inherent resistance to lateral forces is determined by its basic plan layout. . . .*

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[5] One of the five founding partners of Ove Arup & Partners

> *"Engineers are learning that a building's shape, symmetry and its general layout developed in the conceptual stage are more important, or make for greater differences, than the accurate determination of the code-prescribed forces. . . ."*

Structural engineer William Holmes, writing in 1976, states:

> *"It has long been acknowledged that the configuration, and the simplicity and directness of the seismic resistance system of a structure, is just as important, if not more important, than the actual lateral design forces."*

Henry Degenkolb (the late engineer well known to many Caribbean engineers) is emphatic in stressing the importance of configuration, but also recognizes that seismic design is but one of many influences on the shape of the building:

> *"If we have a poor configuration to start with, all the engineer can do is to provide a band-aid -- improve a basically poor solution as best he can. Conversely, if we start off with a good configuration and a reasonable framing scheme, even a poor engineer can't harm its ultimate performance too much. This last statement is only slightly exaggerated. Much of the problem would be solved if all structures were of regular shape, but economics of lot sizes and arrangements, various planning requirements for efficient use of space, and aesthetically pleasing proportions, require the structural engineer to provide for safe constructions of various shapes."*

The nature of the problem has been well stated by the Nicaraguan architect José Francisco Terán, who studied the effects of the Managua (Nicaragua) earthquake of 1972:

> *"The question arises as to whether the building should be designed to meet the functional, social, and aesthetic needs and then be implemented for structural safety or if in seismic areas like Managua, the special problems of stability and overall integrity should condition the design process by which the elements of form such as mass, symmetry, modulation, etc, are decided.*
>
> *"If we agree that such is the case, how can architects, engineers, owners, and the whole community develop a common design attitude for a phenomenon that occurs critically at considerable time intervals during which many of the design parameters actually change? Besides, in contrast with the automobile, the ship, and the air plane that are designed primarily to be in motion during their functioning periods, buildings are designed to be static but may be subjected to short dangerous periods of violent motions.... The more simple, continuous, symmetrical, straightforward, and repetitive the solutions, the greater will also be the degree of reliability of the motionless structures in which we live and work when they become attacked by seismic motions."*

Those quotations above warrant discussion among the various disciplines involved in the design and building processes. Terán's solutions are for buildings to be "simple, continuous, symmetrical, straightforward, and repetitive". This advice is given not as an absolute, but as a qualitative factor that influences the reliability of the structure. Terán asks for understanding and knowledge among the disciplines, not the imposition of mandatory constraints.

The importance of configuration is well recognised in modern standards which penalise unfavourable configurations through the application of higher factors to the earthquake loads or through demands for more sophisticated analyses. The definitions in standards documents of unfavourable configurations are somewhat subjective. A graphic interpretation of SEAOC irregular buildings requiring more punitive loads or dynamic analyses is given in OHPT[6]-1a,1b,1c,1d. As can be seen, most buildings in practice are irregular in configuration.

2 Structural Systems

The main vertical resisting systems for earthquakes are:

- shear walls;
- braced frames;
- moment resisting (or rigid) frames.

The main horizontal resisting system for earthquakes is the floor acting as a diaphragm.

2.1 Diaphragms

The diaphragm transfers and distributes the horizontal forces of the earthquake to the various vertical elements or systems in accordance with their relative stiffness and dependent on their positions relative to the centre of rigidity of the building or portion thereof. This latter determinant has to do with torsional effects. Penetrations are commonplace in floor slabs. The designer must understand the action of the diaphragm to appreciate the effects of such penetrations (OHPT-2).

2.2 Shear Walls and Braced Frames

These systems act as vertical cantilevers. Their lateral load-carrying function is to transfer the horizontal diaphragm loads to the foundations (OHPT-3). Favourable and unfavourable arrangements of shear walls are shown in OHPT-4.

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[6] Overhead projector transparency

Braced frames act similarly to shear walls. The most common material for braced-frame construction is steel in the form of rolled sections or tubes. Where diagonal bracing is used, the braces in compression are sometimes ignored because of buckling. Where the bracing is in one direction only (within the plane of the braced frame) the diagonal member must be proportioned to prevent buckling when in compression.

2.3 Moment Frames

Moment-resisting frames counteract the horizontal forces of earthquakes through the bending strengths of the beams and columns connected rigidly at their junctions with one another. Of course, this bending is accompanied by shear forces. From an architectural standpoint, moment resisting frames have positive and negative implications:

- They allow greater flexibility than shear walls and braced frames in the functional planning of the building – positive.
- They exhibit greater deflexions than shear walls and braced frames so that the detailing of non-structural elements becomes more problematic - negative.

2.4 Non-structural Components

It is commonplace for engineers to ignore the "structural" effect of these elements. In some cases the non-structural elements provide accidental strength to the building. They may, however, interfere adversely with the structural behaviour of the essential load-carrying structure. This could lead to unanticipated overstressing of essential load-carrying members.

3 Basic Configuration Issues and Structural Response

The ***size*** of a building is a factor in earthquake-resistant design. It seems self-evident that smaller buildings can tolerate greater liberties in configuration and detail. Having said that, it is a fact that historically the majority of deaths in earthquakes have been caused by small houses collapsing on their occupants. Thus, complacency is not warranted when dealing with small-scale buildings.

The ***height*** of a building in an earthquake (which exhibits horizontal forces) is analogous to the length of a cantilever. It is self evident that increasing height increase the earthquake-resisting problem exponentially, all other things being equal. Height affects the natural vibrating period of the building. The higher the building the longer its period. Depending on the nature of the earthquake and the nature of the founding soils, increasing the period may increase or reduce the response of the building.

Earthquakes move as waves through the earth's crust. If the building has great ***horizontal dimensions***, the differential arrival of the wave in different parts of the building could pose problems. These could conveniently be alleviated by the introduction of separation joints.

Limiting the ***height/width ratio*** to 3 or 4 keeps the overturning problem within reasonable bounds. In particular, large overturning moments on narrow footprints can lead to high compressive forces on outer columns. These can be very difficult to deal with.

An important characteristic for earthquake-resistant buildings is ***symmetry***. This characteristic applies to horizontal plan shape as well as to vertical elevation shape. (See OHPT-5.) There are many cases of false symmetry where the centre of mass of the building does not coincide with the centre of resistance, although the outward appearance of the building may be symmetrical (OHPT-6).

Another favourable characteristic of earthquake-resistant structures is ***redundancy***. Redundant structures provide multiple load paths so that the premature failure of one (or a few) elements would not lead to the catastrophic and sudden collapse of the building. OHPT-7 shows a simple comparison of a similar plan with low and high redundancies in the structural systems.

The most favourable locations of vertical elements for resisting horizontal loads is at the ***perimeter*** of the building. This is so because such locations provide the greatest lever arm for resisting overturning moments (OHPT-8).

The ***soft storey*** concept is very dangerous in earthquakes. A soft storey may be conveniently defined as one where the stiffness is less than 70% of the storey above it. This commonly occurs in multi-storey offices and hotels due to the desire for higher ceilings and more open spaces on the ground floor. Several design strategies are available for dealing with this situation (OHPT-9).

A non-structural detailing method for in-fill block walls often produces ***short columns***. These columns absorb more than their anticipated share of the lateral loads from earthquakes, leading to shear failure.

Separation joints are used for several reasons in buildings. When this is done the joint between the adjacent parts of the building must be sufficiently wide to avoid ***hammering*** during an earthquake.

Another issue to be addressed with separation joints is the ***flexibility of mechanical services*** as they cross the joint.

The commonly-accepted aim of good earthquake-resistant design is to bring about “failure” (or yielding) of the beam before failure of the contiguous column takes place. This characteristic is described as ***strong column weak beam***. The common hindrance to this desirable feature is the spandrel beam at the perimeter of a building. This are often quite deep for architectural reasons and can be quite an embarrassment for the structural design.

4 Materials

Desirable features of structural materials for earthquake resistance are:

- high ductility;
- high strength-to-weight ratio;
- homogeneity;
- ease in making full-strength connections.

Based on the above properties, a ranking[7] is given below for buildings of different heights:

	High-rise	**Medium-rise**	**Low-rise**
best	1 - steel	1 - steel	1 - timber
	2 - in-situ reinforced concrete	2 - in-situ reinforced concrete	2 - in-situ reinforced concrete
		3 - good precast concrete (with caution)	3 - steel
		4 - prestressed concrete	4 - prestressed concrete
		5 - good reinforced masonry (with caution)	5 - good reinforced masonry
			6 - good precast concrete
worst			7 - primitive reinforced masonry

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[7] David Dowrick

Check List for the Design Team Led by the Architect

(based on the work of Christopher Arnold)

Inception and Feasibility Stages (RIBA work stages A&B)

The architect reviews the project with the engineer before any design begins. Matters to be addressed are:

Issues for Review:

Building size:	gross area	
	floor area	
	probable number of floors	
Site characteristics:	geology	
	zoning restrictions:	
		plan area
		height limit
	orientation	
	foundation characteristics	
Interior planning:	types of spaces:	
		large
		small
	circulation requirements:	
		vertical
		horizontal
	special planning requirements	
Fire standards:	code options	
Budget:	general level of quality	

Structural decisions:

Seismic code:	determination of applicable code

Outline Proposals (RIBA work stage C)

The architect reviews the following matters with the engineer very early in the development of the building configuration. Complex plans or significant configuration issues should be brought to engineer's attention at the earliest possible point so that their implications can be assessed.

Issues for Review:

- Configuration: shape
  - size
  - number of floors
  - significant configuration problems
  - floor-to-floor heights; variations

- Vertical circulation: stairs
  - elevators
  - cores:
    - size
    - location

- Mechanical systems: general type
  - distribution pattern
  - required space for ducts

- Materials: code requirements
  - cladding

Structural decisions:

- Structural strategies: horizontal framing
  - vertical framing
  - lateral systems:
    - moment-resistant frames
    - shear walls
    - braced frames
  - perimeter requirements
  - special aesthetic requirements

Scheme Design (RIBA work stage D)

Matters for consideration are:

Issues for review:

- Architectural systems: exterior cladding
  - interior partitions
  - ceilings
  - depressions in floor slabs
  - vertical transportation

Mechanical/Electrical:
- airconditioning and other distribution networks
- preliminary duct sizes and locations
- openings in floors, walls, beams, girders
- equipment locations:
  - roof
  - floors
  - basement
- vertical shafts
- lighting

Structural decisions:

Structural system:
- bay size
- horizontal framing:
  - materials
  - foundation requirements
- vertical/lateral framing
- shear wall / braced frame locations

Preliminary analysis:
- preliminary member sizing
- preliminary seismic details

Detail Design and Production Information (RIBA work stages E&F)

Matters for consideration are:

Issues for review:

Architectural systems:
- interior partitions
- exterior cladding
- ceilings
- vertical shafts
- stairways
- floor slab depressions

Mechanical/electrical:
- responsibility for seismic safety
- duct size and locations
- piping size and locations
- size, weight, location of all major equipment
- all required penetrations of floors, roofs, walls, shafts, beams
- lighting systems

Structural decisions:

Structural design: member sizes, locations
final structural analysis
connection details
review of shop drawings

Moment Frames

- They allow greater flexibility than shear walls and braced frames in the functional planning of the building -- positive.

- They exhibit greater deflexions than shear walls and braced frames so that the detailing of non-structural elements becomes more problematic -- negative.

Materials

❍ high ductility;

❍ high strength-to-weight ratio;

❍ homogeneity;

❍ ease in making full-strength connections.

A3.3 Problems Associated with Construction and Detailing

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1 The Consulting Engineer and the Builder

Introduction

In the beginning life was simple. There was the master builder who designed, costed and built. Collaboration and coordination were automatic. Then the designer separated herself from the builder and called herself "architect". The designer then became two persons - the architect and the engineer. In the British Empire the quantity surveyor was the next to arrive on the scene. The design engineer became several persons and the builder did likewise.

"Civilization is built on specialization. Specialization may destroy civilization"
Ove Arup

With this large army of different specialists there is the need for very deliberate steps to be taken so that the end result is achieved. What end result should we aim at?

The construction industry embraces all the activities which shape our physical environment. This environment is a product of our way of life and in turn it influences our way of life.

For better or for worse, Mankind is now in control of large parts of Planet Earth. Some may say that Mankind's battle with Nature has been won. If so, we must now administer the conquered territory. This, indeed, is a daunting task which imposes almost impossible responsibilities on us. One of these responsibilities is to *build well*.

What are the essential attributes of a good building? A good building must:

- function well;
- look well;
- last well;
- cost little.

How can relationships within the construction industry be improved to facilitate the fulfilment of this responsibility?

1.2 Design and Execution

It is convenient to distinguish between the design and execution of the total construction activity, although both are inseparably involved with *building well*. The total design is the sum of all of the decisions on forms, systems, materials and construction processes. It is presented by way of drawings, specifications, models and oral exhortation. Execution is meant to be the faithful implementation of these instructions so given.

Design is critical to the total construction process. It is a complex mental process of satisfying a brief with available means. Knowledge of materials, processes, construction techniques and site conditions are a start. The brief must be absorbed, questioned and supplemented. The imagination goes to work. Intuition, invention, ingenuity and just plain experience are called upon to produce a series of steps towards a final solution - a solution which cannot be obtained mathematically, since there are more unknowns than equations, and which is not the only possible or good solution.

Nowadays all of this designing is being done not by one person or entity but by a team of specialists. Good collaboration among the members of this team is necessary if we are to produce very good work. The lack of proper integration of the designs of parts of the whole project is responsible for much mediocrity and wastage in today's construction industry. The process of integration should also extend to the client and his representatives.

Should we succeed in designing well, we must then tackle the greater task of bridging the gap between design and construction. As an aid to better projects the designers should have a good knowledge of the costs of various means of construction. The prevailing system of quantity surveying in the Commonwealth Caribbean serves to separate the designer from the builder; allows construction to start before the design is done; allows the designer to be ignorant of construction methods and costs; and lulls the client into the delusion that his affairs are in safe hands.

1.3 Alternative Approaches

How best can we benefit at the design stage from the valuable knowledge and experience of builders? One approach would be to pay a fee to a builder to join the design team as the specialist on construction methods and costs - a *consultant builder*. The consultant builder would provide the definitive, pre-tender, cost estimate. The consultant builder would still be allowed to tender as a contractor on the project. Should no bid be received as low as the pretender estimate the consultant builder, wearing the contractor's hat, would be required to construct the works for that sum. This method has been used on the Calgary Stampede and other large projects in Canada.

That system is not ideal because of the lack of commercial independence of the consultant builder. If the organisation of construction were an independent profession, merged with the design team, that would take care of that objection. The consultant builder would then be precluded from advising any of the contractors tendering on the project for which consulting services were being provided. Nor would the consultant builder, wearing the contractor's hat, be allowed to tender on the works.

However, we do not have such a system in place at the moment so we must aim to improve the collaboration of the various members of the loosely-knit team as presently formulated.

1.4 Collaboration

What has hindered the development of innovative and economical forms of construction is the fragmentation of the building industry. In no other industry is design divorced from production. The best designs are firmly anchored to the method of execution.

Architects, engineers and builders need to have mutual respect for one another. They need to recognise that all have valid contributions to make. Collaboration must be the guiding principle.

Senior and intermediate engineers tend to keep in touch with builders through site meetings and inspections. Designers could probably spend their time on site more efficiently and profitably by discussing construction problems with tradesmen and supervisors. Such dialogue between the designer and the man at the sharp end would profit both parties and lead to more-suitable designs and more-faithful construction.

1.5 Fairness

1.5.1 Fairness in the Tender Process

If we are to remove cynicism from the industry, and provide real market-driven competition to building owners, we need to ensure fairness and transparency in the processes of tendering and the awarding of contracts. Some of the issues to be addressed include:

- List of tenderers
  - limit the size
  - do not use “stalking horses”
  - conduct preliminary enquiries
- Tender documents
- Time for tendering
  - eliminate holiday periods
- Pre-tender conference
- Opening and assessment
- Notifying results

1.5.2 Supervision of Construction

The purpose of inspections is to check that the work complies with the drawings and technical specifications and that the construction is sound, especially those parts which will be hidden as the work proceeds.

Inspections should be approached with a clear understanding of the intention of the design, obtained from study of the complete set of contract documents, including drawings and specifications. Inspections should be undertaken recognising that, even with care and goodwill, mistakes can arise which may lead to defects. The inspecting engineer should therefore aim to encourage the standard of work required so that defects are avoided in the first place.

Among the items of construction which should receive attention are:

- quality of materials and components;
- dimensional accuracy of the construction;
- correct assembly of structural components and their connections.

Inspections should be made with an open mind, a critical eye and a measure of commonsense. Judgement should be exercised in determining what is acceptable variability based on an understanding of the standards that can be achieved in practice.

Periodic visits should be made to the site during the course of construction to establish that the works are being constructed generally in accordance with the drawings and specifications, and otherwise in accordance with good practice. The frequency of these visits would be dependent largely on the programming of construction for the works, but also on the competence of the builder.

The engineer should examine the implications on the structural design of specialist sub-contractor's details, should check and approve the shop drawings prepared by structural steel fabricators, and should examine changes in methods of construction when proposed by the builder.

The engineer should attend contract meetings held on site during the course of construction for the purpose of coordinating all aspects of the construction.

The engineer should advise on the technical aspects of the builder's interim claims for payment for structural and civil engineering works.

The engineer should provide the owner with a complete set of as-built drawings of the structural and civil engineering works at the end of the maintenance period.

At practical completion of the project the engineer should prepare a list of remaining and remedial works. At the end of the maintenance period the engineer should participate in the final inspection of the project and provide technical advice on structural and civil engineering matters which may be in dispute.

1.5.3 Unforeseen Site Conditions

All too often there is inadequate, or non-existent, site investigation prior to design, tender and contract award. This commonly leads to:

- project time over-runs;
- project cost over-runs;
- disputes.

All sites should be investigated and the factual results communicated to bidders.
It is not uncommon for owners to balk at the expenditures for site investigations. However, you pay for a site investigation whether you have one or not.

1.6 Quantity Surveying

The gap between design and execution is presently almost unbridgeable, preventing the designer from obtaining first-hand knowledge of the costs of various means of construction - an essential requisite for original and inventive designs. The prevailing system of quantity surveying only makes matters worse. It erects a barrier between the designer and the builder.

Realistic cost estimating should become an integral part of the design process - not the sort of costing done in traditional quantity surveying but costing based on the required manufacturing and construction processes. This is especially important with novel designs, new materials and innovative methods of construction. Indeed our traditional quantity surveyors lack the background to fit them for such a role, although such shortcomings do not deter them from promoting their "expertise".

Too often quantity surveyor's estimates are based on what builders have quoted on other occasions for various fictitious items taken out of their context. What is needed are estimates based on the operations, plant, materials, labour and management needed to carry out the particular job at hand.

Estimates are usually done after the design concept has been set. This is too late. A high estimate at this stage leads to the *ad hoc* cannibalisation of the design. It would be better to have an iterative process during all of the design stages, with the quantity surveyor providing continuous feedback, and advice, on the cost implications of all design proposals.

The traditional bill-of-quantities approach to awarding contracts (allowing as it does for construction to start before the design is completed) leads to confusion, delay and extra expense. It encourages

designers to delude themselves that they can create masterpieces without worrying about how pieces are to be put together.
These over-elaborate bills of quantities are a clumsy method of defining the builder's responsibilities, which can be done better by full sets of construction details.

Lastly, good “buildability” is not reflected in the bills of quantities prepared by the Standard Method of Measurement. Therefore, a well-thought-out design incorporating favourable constructional features would not benefit by attracting lower tender prices.

1.7 Innovation and the Builder (OHPT[8]-1&2)

In the construction industry the rapid rise of a new company is usually the result of a talented, dynamic, hard-working leader who outbids the opposition or earns high levels of profit through innovative construction methods. Often the leadership of such a company would pass to a less enthusiastic successor, a professional manager maybe, who tries to maintain the company's edge by fine tuning existing processes. Thus the decline begins. The decline continues when the company's good reputation attracts business on a sole-source, cost-plus basis. This has great short-term benefits but softens the company and dooms it to insignificance. Should the company wish to maintain its competitive edge, however, it would need to foster innovation in its construction methods. It would need to be managed by engineers and not by accountants. On the site the construction manager would need to be someone who knows and enjoys construction, someone who feels more comfortable directing the erection of complex steelwork in the field than writing claims letters in the air-conditioned site office, someone who knows intuitively the correct location for the tower crane.

The average medium-sized contractor does not have enough engineers to do a good job. The various functions to be covered include design, construction methods, cost estimating, contract issues, quality control, testing and even research and development. All of these functions in the construction industry can best be performed by engineers. We just do not have enough of them to go around. Such a team, working closely together, has the ingredients to produce really good work. The designs would take full account of construction processes, costs and contractual idiosyncrasies. In fact these related issues may well dominate the design, which is a situation most clearly seen in large-scale civil engineering projects.

Innovation in design as well as in construction is dependent on:

- the comprehensiveness of the relevant data;
- the quality of the brain of the designer or builder;
- the effort, devotion and enthusiasm applied to the task;
- realism and the critical analysis of mundane and practical issues.

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[8] Overhead projector transparency

1.8 Better Engineers and Designers

Buildability is at the centre of good design. Buildability is the extent to which a design facilitates ease of construction. Some of the issues to be considered here are:

- congestion of urban sites;
- technical innovation;
- prefabrication;
- available skills and labour;
- mechanisation.

The guiding principles of design to achieve buildability are:

- investigate thoroughly;
- consider access;
- consider storage;
- keep to a minimum construction time below ground;
- use suitable materials;
- design for available skills;
- design for simple assembly;
- design for maximum repetition;
- design for maximum use of the essential plant;
- design for sensible tolerances;
- design for a practical sequence of operations;
- design for safe construction;
- design to avoid damage to work by following trades.

1.9 Communication and Information

If we do all of this designing well we are still left with the need to get this information to the builder. Care should be taken to prepare full and specific documents to direct the construction. These would include:

- drawings and sketches (the pictures);
- specifications and instructions (the words);
- models and prototypes;
- schedules.

1.10 The Goal is Excellence

We should remind ourselves of the purpose of collaboration between the designers and the builders. It is to produce successful projects. To be successful a project must be well designed. How do we measure this? Decades ago Ove Arup proposed the following simple formula:

$$\mathbf{E = \frac{C+XC+D}{P+S}}$$

where **E** stands for efficiency or excellence; **C** is commodity; **XC** represents commodity in excess of that required, but still of some value; **D** stands for delight, the artistic quality; **P** is the financial price and **S** is the social price. It is very difficult to put values on **XC**, **D** and **S** but we have to try. Certainly our decisions must take account of these issues. To achieve high values of **E** we require better designs, not better accounting. The management of those designs and their subsequent execution would best be entrusted to persons with design and construction backgrounds with an overlay of management education and training.

It is evident that the construction industry is really in need of a lot of shaking up. No doubt that is part of the justification for course.

2 Specific Issues of Detailing

2.1 Ductility

Detailing reinforced concrete structures to achieve the level of ductility required for earthquake-resistant design is a very difficult task in the design office. It is a much more difficult task to execute these details in the field. Especially in the Commonwealth Caribbean where ductile details for reinforced concrete are not yet commonplace, it would be highly desirable for designers to consult with rebar fixers when developing such details.

Since the Northridge (California) earthquake of 17 January 1994 there has been a realisation that structural steel frames also have significant problems of connection details for ductile behaviour in earthquakes. It is traditional that shop details for fabrication of structural steel are done by the supplier. Because of the special (and so far uncommon) requirements of ductile steel connection details, it is incumbent on the designer to provide more information and guidance than usual to the fabricator or to be active (with the fabricator) in the actual preparation of the shop drawings.

There is clearly a greater inspection demand on the consulting engineer when it comes to ductile details. In the case of reinforced concrete, the placing and compaction of the concrete will be difficult but must nevertheless be done thoroughly.

Detailing for ductility will be dealt with at greater length in Session B3.2 of this course.

2.2 Durability

In the erection and installation of lightweight components of buildings, metal connectors are commonly recommended. These may include steel rods or bolts projecting from reinforced concrete members or metal plates of various types not anchored in concrete.

In the case of anchors partially buried in concrete, long-term protection should be applied to the metals before embedment.

In the case of all metal plates or clips used principally in wind-resistant construction, durability is a critical issue. Plates and clips are usually made of thin metal sheets. The thinner the sheet the greater the percentage loss of strength for any absolute amount of rusting. Unprotected steel sheets must not be used. Painted steel sheets are not recommended. Galvanised steel sheets have been known to deteriorate in a decade or less in the marine environments of Caribbean islands. Stainless steel is very expensive.

These issues must not be swept under the carpet but must be faced squarely in the design and detailing of structures. There is also the need for the client to have a say (guided by the consultant) in matters of relative durability and the relative ease and frequency of maintenance and replacement of connectors.

2.3 Construction Details (Documentation)

It is highly desirable that full construction details be provide to the builder by the designer. The exception is where the tradition is for specialist suppliers to prepare the shop details, *eg* windows and structural steel.

Examples of inadequate detailing in common practice in the Caribbean are:

- locations and frequencies of metal roof fixings;

- locations and frequencies of fixings for insulation boards or sheets on roofs;
- thicknesses of metal roof sheets;
- types and locations of hurricane straps;
- numbers of nails or screws for attaching hurricane straps;
- fixing details for window frames and door frames;
- all details for hurricane shutters;
- anchorage details for electrical and mechanical plant and equipment;
- suspension details for light fixtures, suspended ceilings, ducts and pipes;
- flexible detailing where pipes and ducts cross expansion or separation joints.

2.4 Quality Assurance

Quality assurance starts with clearly written specifications developed for the specific project. If so-called "standard" specifications are issued to the builder, how is she to know what to take seriously and what to ignore? At the start of the construction phase of a project the designer knows much more about the requirements than the builder. It is surely not too much to ask if we require technical specifications to be targeted at the particular project to be built.

At the start of the construction phase there should be a meeting between the designer and the builder. This pre-construction meeting is the opportunity for the builder to seek clarifications on the various procedures aimed at controlling and monitoring the quality of materials and construction. If the builder has no questions to ask at such a meeting, there is a good chance that she has not read the specification document.

The control of quality during the execution of the works is primarily the responsibility of the builder. Inspections by the designer are required as assistance in the process.

a **good building** must:

- function well;
- look well;
- last well;
- cost little.

items to receive attention

- quality of materials and components;

- dimensional accuracy of the construction;

- correct assembly of structural components and their connections.

documents for construction

- drawings and sketches
  (the pictures);

- specifications and instructions
  (the words);

- models and prototypes;

- schedules.