Safety in High-Rise Design and Construction

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1. INTRODUCTION

1.1. Pros and cons of high-rise buildings

PRO:

- Only solution in scarce or expensive land situations
- More compact and integrated management
- Easier to provide and maintain services
- Symbolic of human and national aspirations

CON:

- Complex and expensive to design and build
- High density living makes high demands on services
- Higher psychological and social stresses
- More difficult to control risks and handle emergencies

1.2. Race for height

Living and working at height are unavoidable in modern urban environment. Countries around the world are reaching higher and higher towards the heavens.

Many large countries, USA among them, are not joining the height race … or battle. Most residences in USA, UK, and Australia are still single and low-rise, because land for horizontal expansion is available.

Author believes that India, with its unique strengths and constraints must certainly go to high-rise buildings in the urban environment, but must (and will) use prudence and care in this pursuit, and not compete for global recognition in superficial factors.

Table 1. The race for the tallest building

Country	K.L.	Taiwan	Shanghai	Dubai	Jakarta	New York	Shanghai
Height	452 m	508 m	492 m	>800m	558 m	541 m	1228 m
Completion	1998	2004	2007	2008	2009	2010	2020

1.3. Safety in design and construction – Necessity or luxury?

In many countries, concept of safety is still not part of the professionals' imperative. There is also the deeply ingrained feeling myth that safety concerns will lead to greater cost and reduced productivity.

Over the last few decades, it has been proved that safety evaluation and control save money … provided, professionals place worker injury and death at the top of their list. Otherwise, it may become (and remain) a legal necessity and an industry statistic.

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The truth however is that investment in safety is like planting a tree close to the compound wall: The fruit will be slow in coming, not immediate; and the branches will grow beyond the property, not just one-on-one. Which should be quite acceptable for the industry and the nation.

1.4. Some notorious failures of high-rise buildings

(a) Ronan Point, London, 19 May1968

There was a gas explosion in a corner flat at 18th storey of a 23 storey building, assembled from prefabricated concrete panels ("Large Panel System") bolted together. It blew out the walls. The Southeast corner came crashing down, leaving 4 dead and 17 injured. (Fig. 1.)

Investigation led to finding of poor quality control: Gaps were found filled with newspapers rather than concrete. Walls rested on levelling bolts, two per panel; the whole weight of the building was being taken on these bolts. Rainwater was allowed to seep into the joints. [Ref. 1.]

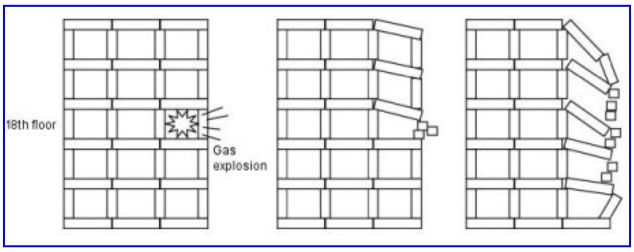


Fig. 1. Chain Reaction Collapse

(b) John Hancock Building Boston, MA, USA, 1973

The 60 storey building, under construction in 1973, was designed by the famous I.M. Pei group. It was beset [Ref. 2] with a number of problems right from the start:

1. Trench walls and shoring collapsed: Sides of the excavation caved in and a nearby church was damaged. The entire trench shoring was strengthened, and the church was re-built.
2. Glass panes started falling off: As and when the wall-sized panels fell, due to thermal expansion and contraction, the open sides were boarded up with plywood. Eventually all the panels were replaced with more appropriate glass.
3. Wind sway led to resonance: Tuned mass-dampers were placed at the top of the building to compensate for the sway.
4. Over-turning about narrow edge was discovered: Heavy cross-bracing was placed around the core to eliminate this unusual possibility.

(c) WTC Twin towers collapse, 11 September 2001

The North Tower (1-WTC) was struck by American Airlines Flight 11, a Boeing 767, at 08:45 Eastern Time. 33 of 59 perimeter columns, and 20 of 47 core columns (centre) were taken down. It stood for 103 minutes before collapsing, pan-cake fashion.

The South Tower (2-WTC) was struck by United Airlines Flight 175, also a Boeing 767, at 09:05 Eastern Time. 29 of 59 perimeter columns and 5 of 47 core columns (SE corner) were taken down. It stood for 53 minutes before collapsing, also pan-cake fashion.

The total dead were 2795.

The main reason was that the trusses supporting the reinforced concrete slab softened in the intense heat of the fire from the aviation fuel dumped to the bottom of the lift wells by the planes, and failed. Loss of fire insulation hastened the collapse. [Ref. 3.]

2. SAFETY IN HIGH-RISE DESIGN

2.1. Motivations for building monumental buildings

Buildings are built for function, beauty, fame, profit, commemoration, fun, economy ..., the hierarchy of motivation depending on the owner/developer.

Safety has not been generally considered a critical factor. But in high-rise buildings, the cost in terms of human life in a natural disaster or man-made accident will be so high that life safety must become the foremost consideration, starting from the concept stage.

2.2. Role of designers in structural failures

During a recent opinion poll [Ref. 4] about designers' role in accidents, it was found:

- 60% of accidents studied could have been eliminated or reduced with more thought during design (European Foundation 1991)
- 50% of general contractors interviewed identified poor design features as affecting safety (Smallwood 1996)
- 47% of likelihood of reduction of 100 construction accidents studied, by design changes (Gibb et al 2004)
- 42% of 224 fatality incidents linked to design (1990-2003 in U.S.) (Behm 2004)
- 22% of 226 injury incidents linked to design (2000-2002 in OR, WA and CA)

Investigators and expert witnesses are pointing their finger more and more at designers who, although they might not have caused the accidents, could have eliminated or minimised the risks and consequences of accidents.

2.3. When design intervention is effective

Current philosophy is to integrate all the activities over the life span of a structure: Planning, design (and drafting), construction, use and maintenance, and decommissioning.

It can be shown that over the life cycle of a structure, implementation of safety is easiest and least expensive at the concept stage, and most difficult and expensive after the construction stage. (Fig. 2.)

Thus the designer is an early player, and must be an integral part of the life cycle!

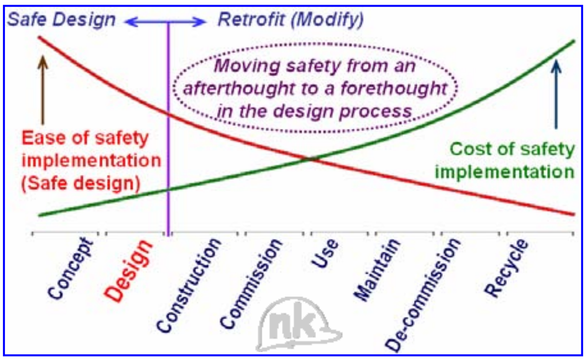


Fig. 2. Effectiveness of safety measures

2.4. Engineers' responsibility for safe design

The increasingly important and critical role of designers is recognised in many design codes of practice around the world.

For instance, BS5950:2000 [Ref. 5] states in 2.1.1.2 Overall stability:

> *"Designer should ensure compatibility of structural design and detailing between all structural parts required for overall stability, even if some or all structural design and detailing of those structural parts is carried out by another designer."* (Emphasis author's.)

UK's CDM Regulations, 1995 [Ref. 6] states (to the extent that it is reasonably practical):

> *"Every designer shall—*
>
> *(a) ensure that any design he prepares ... includes among the design considerations adequate regard to the need –*
>
> *(i) to avoid foreseeable risks to the health and safety of any person at work carrying out construction work ...,*
>
> *(ii) to combat at source risks to the health and safety of any person at work carrying out construction work ...,*
>
> *(iii) to give priority to measures which will protect all persons at work who may carry out construction work ... over measures which only protect each person carrying out such work;*
>
> *(b) ensure that the design includes adequate information about any aspect of the project or structure or materials (including articles or substances) which might affect the health or safety of any person at work carrying out construction work ...; and*
>
> *(c) co-operate with the planning supervisor and with any other designer who is preparing any design in connection with the same project or structure ..."*

Apart from codes and laws, engineers and builders from time immemorial have been assumed to have a "Duty of care", like a doctor has to his patient:

In the author's opinion, while designers may not have the time or the resources to do everything for everybody, they do have a professional obligation, a moral duty, to at least:

(a) Clearly define the boundaries of their commitment, so that no one may innocently or wilfully extend them or assume more than intended;

(b) Document the assumptions they make and the details of computer models they create in their work;

(c) Point out real risks and potential hazards within the scope of their work, and in the tasks that may be related to their design; and,

(d) Review all aspects of their design and rework it as necessary if and when the contractor has difficulty implementing the design, or the owner insists on some sudden change.

2.5. Benefits of designing for safety

Although all the benefits of designing for safety may not be immediately obvious, the following are broadly recognised:

- Safer workplaces
- Reduced workers' compensation premiums
- Better conformance with health and safety legislation
- Increased productivity
- Improved innovation
- Reduced costs
- Fewer delays due to accidents during construction allowing continued focus on quality
- Positive response to pro-active clients demanding safer construction and safer designs
- Improved industry image and national prestige

However, all these primarily depend on professionals’ value system!

2.6. Barriers to designing for safety

Incorporation of safety into design will not be easy however. Many obstacles will slow down the process or wipe it out. Some of the barriers, apart from the cost at front end are:

- Fear of liability
- Designers’ lack of safety expertise
- Designers’ lack of understanding of construction processes
- Increase in professional fees
- Rigid contract terms (– Presently forbidding designer intervention, in some codes!)

All barriers would of course have to be overcome, if people are to have a safe high-rise building.

2.7. Factors in safe design

Apart from satisfying all applicable codes, factors to be addressed for safe design are:

- Realistic modelling
- Constructability
- Redundancy
- Design for maintenance
- Unusual and overlooked loadings
- Effective use of computers
- Demolition

2.8. Realistic modelling

(a) Centre-line modelling:

Modelling of eccentricity, step, and haunch in structures with large-size members is often done in *ad-hoc* manner, taking the easy way out by neglecting what is perceived to be insignificant variations along the centre lines.

Consequences, while generally minor, may become cumulatively adverse. (Fig. 3.)

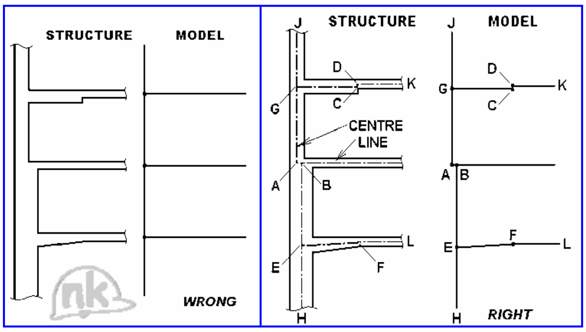


Fig. 3. Realistic modelling

(b) Rigid joint zones:

Another common practice is (knowingly or unknowingly) to ignore the effect of modelling wide regions (such as RC beams and columns) by straight lines. (Fig. 4.)

These may be generally conservative, but apart from decrease in economy, there may be unusual loading combinations which may actually have an adverse impact.

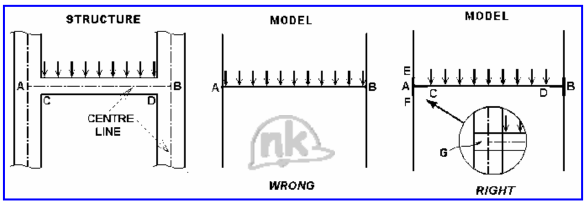


Fig. 4. Rigid joint zones

Computers have built-in features to handle these variations. But users must first learn and then remember to use these features; they must specify and input them appropriately!

2.9. Design assumption versus reality

At each stage of design, the designer has to ask:

(a) What are, or should be, the support conditions of beams: Fixed, pinned, roller, free?

(b) What are, or should be, the rigidity of connections: Full, partial, none?

(c) What are, or should be, the end conditions (restraints) of columns: Full or partial, in position and in direction, in each plane?

Can these assumptions be implemented in practice?

It is generally overlooked that semi-rigidity of connections cannot be properly computed, and must be determined from tests for the particular configuration chosen. (Fig. 5.)

This is particularly critical in temporary structures, where erection procedures and inspection are not of the same order of quality control as the permanent structures.

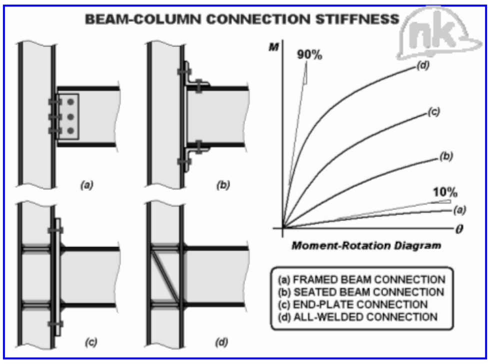


Fig. 5. Rigidity of connections

2.10. Constructability

A common oversight in design (even today, even in advanced countries!) is the lack of integration of the design with the construction phase. Quite often, once the designer submits his calculations and drawings to his client, his responsibility is assumed to be over, by all concerned.

In this context, the contractor is often stuck with an item or a detail which cannot be constructed as exactly per the design.

Then, either the contractor proceeds with whatever alternative solution he can come up with, or he refers back to the designer, who does a cursory re-design and sends it back – both of which will more often than not lead to trouble.

(a) ***Hyatt Regency walkway collapse, Kansas City, Missouri, USA, July 17, 1981:***

Built in July 1980, there were two walkways in the 4-storey atrium of the 40-storey tower. {Ref. 7.]

On the fateful day, a party was going on, when the upper walkway crashed on the lower one, and both collapsed to the floor. 114 were dead and 200 were injured. (Fig. 6.)

And the cause?

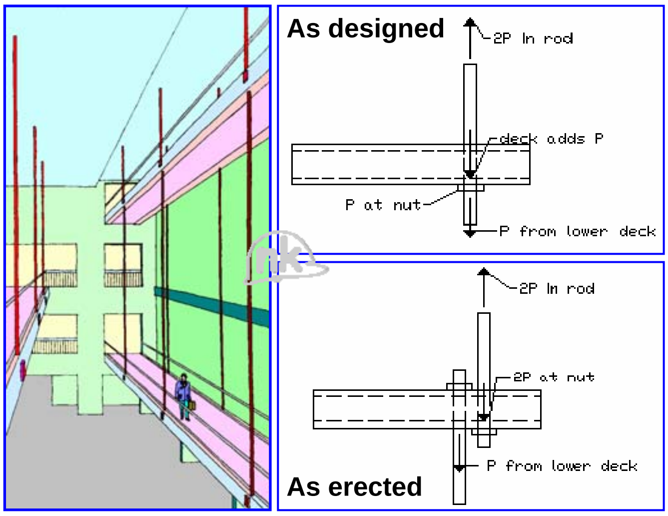


Fig. 6. Hyatt Regency walkway collapse

A single long tension rod had been replaced by two shorter tension rods, both same size, and both connected in the normal way.

The contractor, who thought that threading a long rod for most of its length to fix the intermediate nut, did pass his revised design through the designer, and the latter presumably approved.

A careful check of the force distribution on the nut by First year B.E. or Diploma level statics could have shown that the load on the washer and nut at the upper walkway was *P*in the first case, and 2*P* in the second.

A costly lesson on the importance of basics in these sophisticated times!

(b) Hartford Civic Center Arena roof collapse, Hartford, Connecticut, USA, 18 January 1978:

The roof was 300 ft. by 360 ft. space frame, completed on Jan. 16, 1973. [Ref. 7.]

It was assembled from 30 ft. by 30 ft. grids, 21 ft. apart. Main members were of cruciform shape, which happened to be possibly the most inefficient. (Fig. 7.)

On January 18, 1978 the largest snowstorm of its five-year life hit the arena.

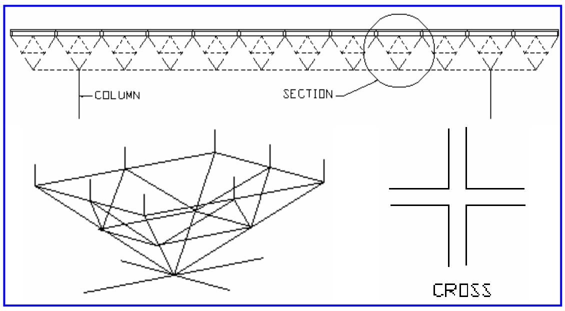
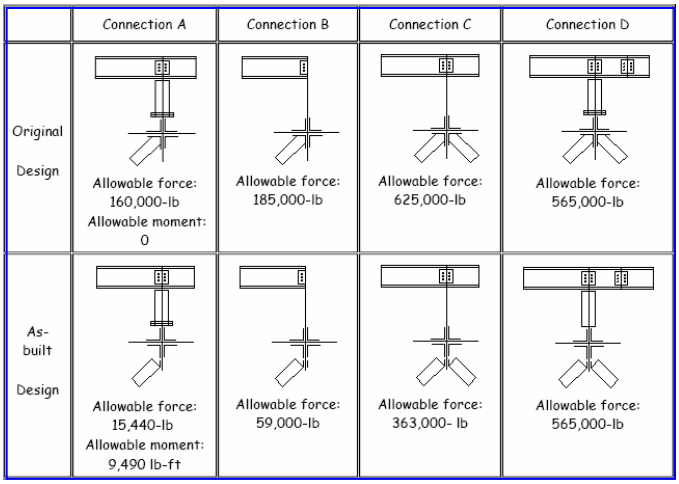


Fig. 7. Hartford Civic Center Arena

At 4:15 A.M. with a loud crack the centre of the arena's roof crashed down 83 feet to the floor of the arena, throwing the corners up in the air.



	Connection A	Connection B	Connection C	Connection D
Original Design	Allowable force: 160,000-lb Allowable moment: 0	Allowable force: 185,000-lb	Allowable force: 625,000-lb	Allowable force: 565,000-lb
As-built Design	Allowable force: 15,440-lb Allowable moment: 9,490 lb-ft	Allowable force: 59,000-lb	Allowable force: 363,000- lb	Allowable force: 565,000-lb

Fig. 8. Connections as designed and as built

Luckily the arena was empty.

Again the reason was that the contractor could not physically make the connections as designed.

He made some “minor” changes, shifting some connections a few centimetres. (Fig. 8.)

A re-analysis (the second time by the same program as the original design, but with the revised connection detail) showed that considerable capacity had been lost by the change.

That it held up for so long was pure luck of the design snow storm not occurring for that long. That there was no game going on was a miracle!

(c) Connection detailing:

The preceding is just one dramatic example of what goes on in many of our trusses and other connections, bolted or welded.

Trusses are usually analysed and designed on the assumption that the centroidal axes of all the members meet at a joint at a single point, to satisfy the assumption that the members are subjected only to axial forces. (Fig. 9.)

Fig. 9. Truss connections

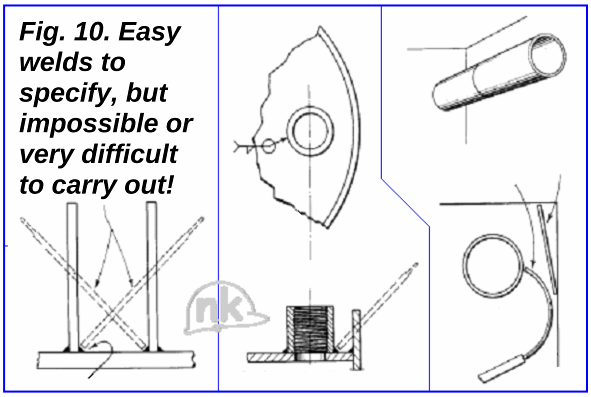


Fig. 10. Easy welds to specify, but impossible or very difficult to carry out!

But due to practical considerations, centroidal axes generally may not intersect at a single point.

Generally the resulting moment effects are negligible, but the situation needs to be checked so that the deviations and consequences do not get out of hand.

Welding detailing is likewise very much practice oriented, and a designer may casually ask for impossible things, as illustrated in Fig. 10.

2.11. Redundancy

Redundancy is the provision of alternative load paths in a structure to enable it to survive a limited accident and prevent a member failure from escalating to structure collapse. This is generally advisable in life-critical structures but rarely followed, on the grounds that it would take extra time and cost extra money.

Designer should analyse scenarios with different critical members omitted, to track down the effects on the system.

An example of how redundancy saved a temporary structure occurred during roof truss erection for the FedEx Forum building in Memphis, Tennessee, USA, in 2005. [Ref. 8.]

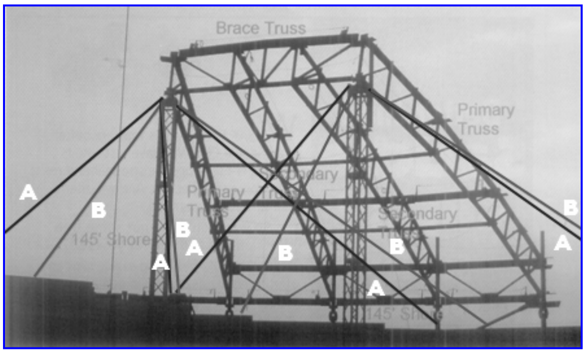


Fig. 11. Redundant temporary structures

Based on a storm warning, the contractor added five back-up cables (B for each A, in Fig. 11) to hold up the partially erected truss for redundancy, helping it to withstand more than twice the design wind load which developed overnight, while other temporary structures around it collapsed.

Again, it was redundancy of columns that saved the New York WTC from immediate collapse after the terrorist collapse. When many columns were sliced through by the plane hits, the many external steel mullion tubes of the windows shared with, and redistributed the loads to, the inner core columns through the medium of the floor slabs and trusses.

This also brings up the question whether the Twin Towers were designed for any airplane impact. It is understood that they were, for the very planes that hit them. However, the airplane impact was for normally predictable landing problems, namely with near empty fuel tanks and at slow speeds, and not the terrorist hit, with full tanks and at maximum speed.

An incidental but important lesson here is that although theoretically structures can be designed even for heavier and faster airplane hits – just as they can be designed for 100-year earthquakes rather than for 25-year earthquakes as at present – the costs of such designs would be so prohibitive that few if any owners or tenants can afford them, and the members would be so huge that the percentage of usable space would drop by a large ratio.

2.12. Design for maintenance

High-rise buildings will serve better and longer if they are inspected and maintained at regular intervals. But these activities are not often considered at the design stage.

For inspection and maintenance to be safe activities, anchors and accessories may be designed during design and implemented during construction, more simply and economically – and safely – than during each time the activity is to be carried out.

- Appendix C to Subpart M (Fall Protection) of OSHA Standards for Construction recommends: *"Anchorage points can be incorporated during construction, for use then and later for window cleaning or other building maintenance."* [Ref. 9.]
- Sloping or curved roofs to have embedded anchors at convenient locations.
- Ceilings in interstitial space designed to be walkable and allow worker access.
- Floor finishes underneath raised metal floors designed to be smooth and easy to crawl across.
- Permanent guardrails to be installed around skylights.
- Air-conditioner compressor units, presently mounted outside each room or office, may be grouped from a certain number of floors and located in intermediate floors, to provide safe access and working area for the service personnel.

2.13. Overlooked and unusual loadings

Overlooked loadings on permanent structures may be the following:

(a) Overlooked loads:

- Wind uplift → Hurricane uplift in USA
- Increase in reactions at penultimate supports of continuous beams
- Increase in moment due to partial loadings on continuous beams

(b) Modifications of Usage:

- Overloading, like a heavy crowd assembling on a private residential balcony to watch an unusual activity on the road below
- Rearrangement of furniture on a thin floor, which can cause fresh resonating vibrations [Ref. 10].

(c) Terrorism, a new criterion:

The terrorist attack and resulting collapse of the World Trade Center Twin Towers in New York on September 11, 2001 introduced a new dimension to the safe design of high-rise buildings.

To be realistic, buildings, bridges etc. cannot be designed to actually take and survive terrorist attacks of any large magnitude. However, consequences can be mitigated and loss of lives minimised by the following measures, recommended by experts after extensive debate:

1. Include terrorist activity into the hazard analysis and risk assessment.
2. Continue the good practice of redundancy.
3. Increase egress size and protection.
4. Improve fire protection and inspection.
5. Tighten up and expand emergency preparedness.

(d) Overlooked construction loadings:

Temporary structures and partially completed permanent structures are highly susceptible to failure by unusual combination or type of loadings not designed for.

Radial struts of a partially erected dome, yet unclad, rotated in the plan, thus allowing the twisting of the top central compression ring, causing the dome to collapse inwards. (Fig. 12.)

Luckily no one was inside at the time.

Incomplete foundation anchorages, connections, bracings, ties etc. may often result in structural elements not having developed the full strength or stiffness.

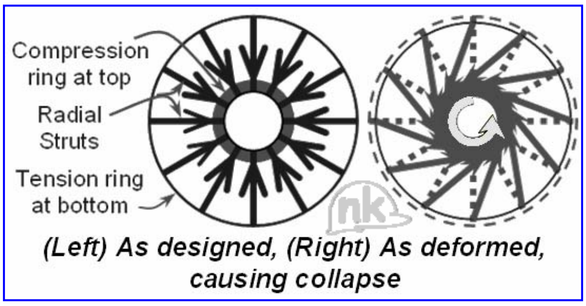


Fig. 12. Twisting of dome ribs

2.14. Prevention of progressive collapse

Designer must prevent a minor localised failure escalating in domino fashion into a complete system collapse, for a permanent or temporary structure. Codes usually highlight this need.

Safeguards and/or alternative load paths must be provided to contain the damage, so that occupants may exit and valuable property may be removed as soon as one or a few members fail.

Design must include bracings against buckling of individual members, and sway against system collapse.

In temporary structures, one bay or member may fail, and it can drag down the entire system. The cause may be missing bracings or anchors against sidesway.

3. EFFECTIVE USE OF COMPUTERS

3.1. Hidden dangers of computer use

As one with computer experience from 1959 (and still using them in his consultancy and training) the author is deeply concerned with the way computers are used for structural analysis and design these days. This can have a far-reaching impact on high-rise buildings.

The case study by an expert should demonstrate the seriousness of the situation. (Fig. 13.)

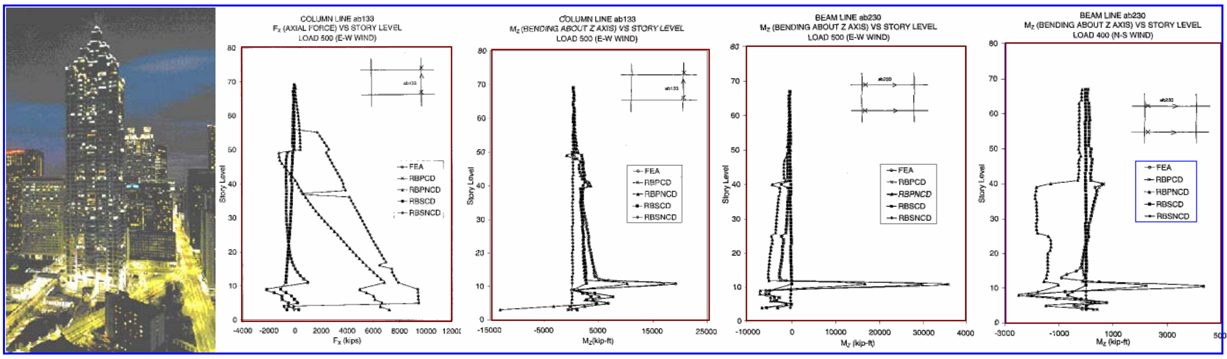


Fig. 13. Axial force and column moments under E-W wind; beam M_z under N-S wind

Professor Leroy Z. Emkin of GeorgiaTech, well known computer software specialist, and founder of the group responsible for GTSTRUDL, one of the oldest and best known structural software packages, conducted the static analysis of a 67-storey commercial building (by GTSTRUDL, naturally) with different models. [Ref. 11.]

Figure 13 shows the axial force and bending moments on the columns under E-W wind, and beam moment under N-S wind.

Wide (and wild!) variations in critical results are clearly visible in the charts.

With further investigation and data adjustments to reflect known conditions, the results may possibly be brought closer together. But the results show what can happen with routine computer application to a complex problem, and how misleading it can get if results from a single analysis are adopted as the correct solution.

3.2. Risks in computer use

The advantages of computers in structural analysis and design are well-known. Against the many benefits of computers are the following limitations, concerns and disadvantages:

- The computer does not analyse a structure. It only manipulates numbers representing a model of the structure we give it, based on standard formulas and built-in logic.
- Modelling of complex structures is as much an art as a science, depending on many varied factors, requiring great care, and experienced personnel.
- Results will depend to a large extent on the model.
- Interpretation of results is also likely to be complex and subjective in many situations.
- As computer use increases, basic principles and assumptions of structural analysis are forgotten.
- As computer packages increase automation, we lose sight – and the “feel” – of significance of data.
- Modern software and hardware for computer graphics produce such sleek multi-colour drawings that the eye and the mind often skip over flaws which would have been obvious to a pre-computer generation.
- Unless the designer himself inputs the data, operates the computer, and interprets the output, the designer is one-step removed from his work and from the completion of his obligations.

3.3. General cautions on computer usage

- Computers are here to stay. The more “automatic” and sophisticated that hardware and software get, the more careful and “smart” engineers in general, and designers in particular, must become to make proper and full use of the hardware and software.
- Do not accept computer results of complex and critical problems at face value – especially where human life and health are involved, as in scaffolds.
- Always insist that the analyst submit details of the computer model with the results.
- Have a rough manual and approximate check on crucial results, which should confirm the computer result at least to the same order of magnitude.
- Ask for details of design assumptions and computer models.

- Designer must check drawings and approve changes.

4. SAFETY IN HIGH-RISE CONSTRUCTION

4.1. Temporary structures

Most accidents in high-rise buildings (as with most structures) occur during the construction phase.

That is because, in general, temporary structures and processes used in construction are more susceptible to failure than permanent structures themselves:

- “Temporary” nature psychologically leads to neglect.
- Materials, procedures, inspection etc. for temporary structures are all under less scrutiny and control.
- Foundations for temporary structures are also less known and under less control.
- General public rarely gets to see them or use them.
- Personnel involved are mostly uneducated labourers.
- Temporary structures may not be subject to rigorous codes (in countries like India).
- Personnel involved are not the ultimate users and hence have no vested interest in their deficiencies.
- They have no direct benefit to users after construction.
- Cost is not a main line item to client, and must be absorbed, to be amortised over repeated uses.
- Must be dismantled and reused many times, their components get damaged at critical locations.
- Scaffolds are considered so simple they need no attention.
- Design lacks construction instructions or contractor does not follow them.

4.2. Overlooked construction loadings

(a) Varying loadings during construction stages:

- Such as different lifts of concrete casting, removal of formwork, pre-stressing etc.

(b) Loadings during material delivery:

- When removal lags behind delivery
- Crane deliveries on to unplanned locations

(c) Good intentions gone bad, or “unintentional harm”:

When cable guys tied to a tall post to keep it vertical are tightened, the increasing tension in the cables result in a corresponding increase in compression force in the post.

If unchecked, enthusiastic over-tightening of the cables may get so large that the post may buckle. (Fig. 14.)

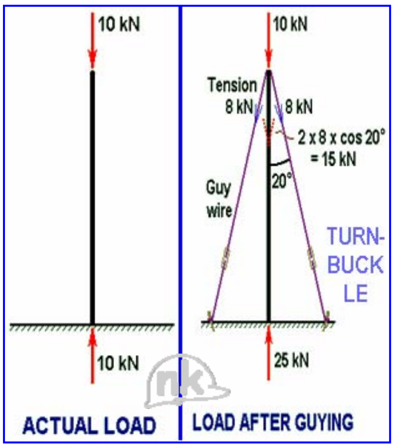


Fig. 14. Post compression

Likewise, with pre-stressed concrete, more pre-stressing is not always better, often worse.

4.3. Assumed and actual connections and supports

As temporary structures have many more deficiencies and uncertainties than permanent structures, their connections and supports are also sources of more danger.

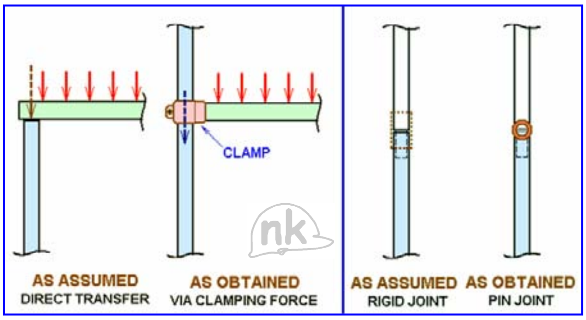


Fig. 15. Connection deficiencies

A bending element which was designed as if simply supported may be actually supported by friction at site.

Connections which are assumed to be moment resistant may not be so, because fittings which were tight when components were new would have lost their snugness and integrity after a few uses. (Fig. 15.)

Hence rigidity or continuity of joints cannot be assumed as a matter of course.

The same is true for support conditions of temporary structures. It may be safer to assume them pinned.

Conditions at column ends and intermediate supports, which determine the *k*-factors, are very critical in temporary structures.

Lateral stability cannot be taken for granted, and special anchors and sway bracings must be designed and carefully implemented.

Foundations have little or no base preparation. They may be further affected by rain.

Trouble arises when design lacks construction instructions or contractor does not follow them.

There are cases where the support conditions assumed in design are not implemented during erection or construction, leading to failure of the structure.

In one instance, truss supports were designed to be roller (slide), but the contractor, with the good intention of securing the trusses against instability during erection, bolted them down to the walls as the crane placed trusses on the walls. (Fig. 16.)

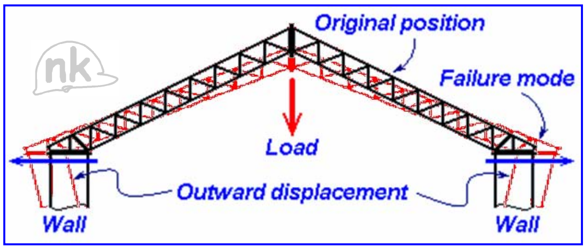


Fig. 16. Truss erection error

When the crane attachment was released and the trusses took their own load, deflecting downwards and spreading their ends outwards, they pushed the walls outwards and knocked them down.

4.4. Unauthorised changes

Contractors often modify or substitute components or the sequence of erection:

- To use available materials or equipment
- To avoid delay, to make up for lost time
- To overcome site or fabrication constraints

But the contractor may fail to inform designer of the changes, or does not send sufficient detail.

Or the designer may fail to appreciate or evaluate the impact of proposed changes on the integrity and safety of his design – as in the case of the Hyatt Regency disaster.

Construction-related trades such as electrical and mechanicals services, plastering, etc., may remove ties or braces from scaffolds, and not put them back, so much so that with increasing number of removals, the scaffold is likely to become unstable and collapse.

4.5. Risk management in construction

Many methods are available to reduce high-rise construction risks. They are usually to be followed according to the following hierarchy, in decreasing order of importance and effectiveness:

(a) Elimination of scaffold risks:

- Apartment blocks are fabricated, or cast and cured at ground level, and then picked up and stacked one on top of another by cranes.
- Walls are case flat on the ground, and after curing, rotated up into position.

(b) Substitution of risky products or processes by less risky ones:

- Climbing formwork
- Mast climbers, single and double (Fig. 17.)

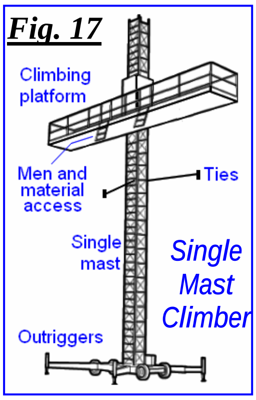


Fig. 17

(c) Engineering controls for risk mitigation:

(i) Stopping workers from falling ("Fall prevention"):

- Guardrails and toe-boards at open sides and around voids
- Roof brackets and slide guards
- Warning lines (tapes) and barricades
- Covers on holes
- Lifelines and anchors for work positioning systems

(ii) Stopping workers from hitting the ground and dying ("Passive fall arrest"):

- Lifelines and anchors for fall restraint and fall arrest systems
- Safety nets and air cushions

Note that lifelines and anchors must be designed and positioned for maximum forces and deflections under worst case scenarios.

Further, the pendulum effect in slipping sideways or from other critical positions and worker hitting the ground or other solid object, must be carefully examined, and lifeline configurations and anchorage points correspondingly provided for. (Fig. 18.)

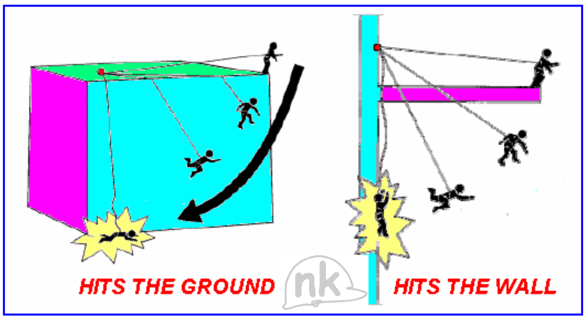


Fig. 18. Pendulum effect from lifelines

(d) Administrative controls for risk mitigation:

- Budget for safety management, training, posters, etc.
- Warning signs
- Safe work procedures

- Rotation of workers while doing fatiguing and difficult jobs
- Tagout and lockout signs

(e) Personal Protective Equipment (PPE):

PPE consists of: helmet, overalls, goggles, ear-plugs, gloves, safety shoes, gas mask, belt, body harness, etc. Belts and harnesses are referred to as “active fall arrest” equipment.

The preceding four controls are for the entire workforce, protecting the workers without their having to do or wear anything individually, but only to follow rules of their proper use.

But PPE is for the individual worker, depending for its effectiveness on the worker individually putting them on, wearing them, maintaining them, and using them every time they are needed, correctly.

Because the worker may not use PPE correctly out of ignorance, negligence, carelessness, over-confidence, or oversight, it is relegated to the last position in the hierarchy. While they are essential, they may be only applied to the individual worker and cannot be depended upon as a general risk control method.

Even with all these risk control measures, there will be some residual risks left. These can be controlled and managed only by strict supervision and inspection, to ensure that the controls are implemented, maintained and applied properly, and that the PPE are used by the workers correctly and all the time!

4.6. Rescue and emergency preparedness

Whether during or after construction, there will be occasions when: (a) accidents affect workers, or, (b) natural or man-made disasters affect residents. These situations are especially critical in high-rise construction. Fires and explosions are common examples of such emergencies.

Good design and construction practice require that safety controls include appropriate rescue equipment and personnel trained in proper rescue procedures. These may include: First aid equipment, tripods and lifting equipment to shift workers from enclosed spaces, resuscitation equipment, fall rescue equipment, etc.

5. CONCLUSION

Peter Blake in *“Form Follow Fiasco”*, [Ref.12] lists the problems with high-rise buildings:

> *“High-rise buildings work against nature, or, in modern terms, against the environment.*
>
> *“High-rise buildings work against man himself, because they isolate him from others, and this isolation is an important factor in the rising crime rate. Children suffer even more because they lose their direct contacts with nature, and with other children.*
>
> *“High-rise buildings work against society because they prevent the units of social importance -- the family ... the neighborhood, etc. -- from functioning as naturally and as normally as before.*
>
> *“High-rise buildings work against networks of transportation, communication, and of utilities, since they lead to higher densities, to overloaded roads, to more extensive water supply systems -- and, more importantly, because they form vertical networks which create many additional problems -- crime being just one of them.”*

Of course, in spite of all these problems, high-rise buildings may be inevitable in modern India.

The author has cited them only to identify the adverse consequences which designers and builders must address in their work in a balanced and integrated manner, rather than to criticise the need and work for high-rise buildings.

High-rise design and construction are topics critical to the development and vitalisation of the urban scene in India. With all its impressive technological advances, Indian construction industry still needs to be organised and integrated to reach its full potential. The nation currently being in the global limelight, how the industry performs in the coming years will to a large extent determine the status of India in the community of nations, to mutual long-term advantage.

The author hopes that the few topics he has raised and discussed herein will provide food for thought in terms of safety in high-rise design and construction in the vibrant Indian context.

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