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1 would like to address the subject of changes in building design, materials and processes as seen from the designer's side. My area of activity is the design of commercial, institutional, and multi-story residential buildings. Structural engineers tend to not get too involved in one-story, single-family residential buildings, but more in the high-rise, multi-level type of construction.

Recently in the New *York Times*, about three or four weeks ago, there was an article about the cost to construct a project in New York City which pointed out an interesting fact: To bring a condominium on line in New York City now runs $300 per square foot. One hundred dollars is construction cost, $100 is land cost, and $100 is interim financing and soft costs.

So we can sit here and address the problem of construction costs, how to do things, how emerging technologies are going to affect construction costs from a design side and a construction side, but we're really only addressing one-third of the situation. The land cost is beyond my ability to discuss, but the financing costs and the length of time and the process from the time you conceive a project to the time you occupy the project is the area in which I think a major revolution is probably going to take place in the next decade. That's probably where the major cost savings and major technological changes will occur. They're not going to be technological in the sense of high tech, but they're going to be more within the process of construction,

I'd like to address the design, materials and processes aspects. From the design point of view, computers obviously are going to be the entity which will revolutionize the design business. It's happening already. The things that Wendel R. Wendel talked about, all of that sort of thing, it's coming rapidly. It's in our office now. It's in a lot of offices — the ability to do these things, do them quicker, do them better, look at more options and alternatives are all here.

But the big revolution is going to be the interfacing of the software in the computer systems within the design office with the rest of the construction team, and right now that hasn't happened. This is where there's really going to be a revolution,

Wendel's doing it because he controls his total destiny. The present design, fabrication, erection and construction process is very spread out, diverse and fragmented, I think the process is going to come together — that's where a lot is going to happen. CAD and computers are obviously going to be a big step in the right direction.

As far as structural engineering of multi-story buildings, as far as floor systems are concerned, we really have reached the optimum. We really can't get any lighter than we have with present materials. We use steel. We use concrete. Anybody that's attempted to get it lighter has had floor levelness problems, deflection problems and all sorts of human-perceptibility-to-motion problems. We have, in my opinion, reached the optimum in floor design.

If we take the example of a typical building, a forty-story, high-rise office building, it takes about ten pounds of structural steel per square foot of floor area to support gravity loads. That's the material in the floors and the columns. But it takes a total of about 20 pounds of structural steel per square foot when you get done. The additional ten pounds of steel is to resist wind. If you go sixty stories or eighty stories, the 10 pounds for gravity loads remains fairly constant, but the contributing portion of the steel material to resist wind loadings is where the big weight increases start to pile up.

We could fool ourselves and attempt to make the floor lighter, but if we're going to get much lighter than ten pounds, we will get sued when the floor deflects or bounces too much.

What's interesting is that Wendel's slides primarily addressed roof structures, enclosure structures and the monumental or the architectural centerpiece of a project, which is the exciting part of the project. However, when you look at percentages of area within a building project, probably five percent of the area is in that part, and 95 percent is the floors. So going back to this point of the floors, I'm not saying space trusses can't be used for floors. We're using truss systems in office buildings now because we're up to 45-foot spans. We want to get mechanical penetrations and make it a 'smart' building. There is one major developer, Oxford, from Canada and the United States, who uses truss systems in all its buildings. There's no reason why space truss systems couldn't be used in the same thing.

Trusses allow you to open up an interstitial space in the floor to allow all of the mechanical systems to go through. Unfortunately, when you compare it to conventional trusses and conventional beams, it's still too expensive, but I think it's going to get there. As more people like Wendel get involved and bring this total capability together, I think there are good chances there.

Moving to the wind system and the NASA group, I'll use one example. Around 1965, as we were designing an 800-foot observation tower in Milwaukee, we sat back and said, "The gravity-load-resisting components of the project constitute about 10 percent of the job." It was not an occupied building — it was an observation tower. Ninety percent of the structural material was required to resist wind loadings. But what is wind loading? Maximum design wind loading is a one-inane-hundred-years mean recurrence interval. We design for a situation that happens once every one hundred years. Now, that could happen next year, which it usually does, but you're putting in 90 percent of the material in a special tall tower to resist a one-in-one-hundred-years occurrence. Why not try a different approach?

NASA, when they move the Saturn V from the assembly building to the launch pad, has a system of servo-mechanism, hydraulically-activated jacks to keep the Saturn V in a fairly vertical position. So we called up General Motors, Delco Division, who did that work, and we asked whether or not it was possible to develop an active system which would sense acceleration, velocity and drift or motion of a tall tower and activate hydraulic jacks in the building connected to cables that extend from the top of the tower to the foundations. So when the building moves, accelerates or displaces, these jacks activate and the building is brought back to a vertical position.

Obviously, the concern is that the system could go out of whack and go in the opposite direction. Because, if the building is moving away from the wind, you want the activated jack on the windward side. If it's jacking on the leeward side, you've got a problem since it will magnify, not reduce, the movement.

Delco came in and priced the system, and confirmed that it was totally reliable. This was 1965. We've come a long way with home computers and other sophisticated control systems since then. My feeling is that this active system approach in taller buildings, to eliminate the need of putting 50 to 90 percent of the material into the building to resist a one-in-one-hundred-years occurrence, is probably an area that people should be looking at. It can be done!

The Citicorp Building in New York City and the John Hancock Building in Boston both have tuned-mass dampers at their tops. Now, these are not active systems. they are really passive systems because they sort of lag behind and slow down the motion of the building. In the mechanical machine design area, tuned-mass dampers have been prevalent for years. A tuned-mass damper is a device that stops vibration. It vibrates out of phase with the building and slows it down. It works in buildings, although it is not really an active system. I think that is one area in which major innovations are going to develop,

Another way to try and do something technologically advanced is to reduce the amount of material in a high-rise building by doing what the home-building industry has done with the use of stress-skin plywood. Stop and think about it. There's no wind analysis done by an engineer on a one-family residence building, right? Wind stability of a one-family residence is inherent in the adhesion of the plywood through nails or glue to the stick-built system. Until the plywood is put on the building, the frame is sort of flexible. The plywood forms a stressed skin.

Well, the skin, using Professor Tucker's figures, becomes one of the two major cost components of a building, along with the structure. If we can integrate the skin or enclosure into a structural system, we can achieve real economy.

We tried it recently on a very successful project in Pittsburgh for U.S. Steel Realty. It was nice that we were working for U.S. Steel Realty; they encouraged us to use an exposed steel solution. It's a fifty-five-story building. It was called the Dravo Building, but then it became the Mellon Bank Center Building. It uses a quarter-inch-thick steel facade. It's the architectural skin with the windows mounted in it. But it's also a valuable part of the structural system. Without it, the drift of the building is double the magnitude that we deem acceptable by human perceptibility acceptance standards. With the stressed steel skin, the movement is reduced to one-half the magnitude.

We have an internal skeletal structure of columns and beams which safely resist wind from a stress point of view. However, the drift at the top of the building would be 36 inches (H/250). When we put the one-quarter-inch-thick steel skin on, it acts as a stressed-skin, and we bring the drift down to 18 inches (H/500).

We ran into an interesting problem in the process. Exposed steel is not fireproof. So we went to the Pittsburgh Building Department and convinced them that the chances of a fire totally enveloping the entire exterior skin on the building were quite remote. By the time that happened, if it could happen, the building would be unoccupied, and if the drift were twice what we felt was acceptable by human perceptibility, there'd be nobody in the building to perceive it anyway, so they accepted it.

It's a new concept. It's a concept of safety versus human perceptibility and comfort. Codes do not prescribe any drift or any acceleration controls. There are no human perceptibility limits on controls within the codes. The codes only address safety.

Both the use of an active system and the integration of the exterior skin in the wind drift control system are areas where I feel the building industry will make major revolutions in the design and construction of taller buildings.

Fireproofing. The steel industry has been wrestling with this problem for years, but if someone could come up with an inexpensive, thin, easily applied, durable fireproofing system for structural steel, I think you would see a major revolution in construction.

The aerospace industry has developed intumescence paints and sublimination coating materials. They're still too expensive. They are available, but somebody should try to develop a low cost fire-proofing coating system that is architecturally acceptable. This would change a lot of what architects do in terms of structural expression. It would eliminate all of the materials that get sprayed on after which everybody spends millions of dollars trying to cover them up so you don't see them. Some of the already available materials, particularly some of these subliming paints, actually look like an enamel finish. They're excellent, but too expensive.

Let's jump to materials. Steel and concrete are the two major structural construction materials. I have attended a lot of meetings with many people who try to introduce composites (fiberglass, boron, and graphite laminates) into the construction industry. The reason it's not coming in, besides the other reasons that Al mentioned, is that concrete costs only six cents a pound; people lose sight of that. It's probably the cheapest, most abundant material around, and steel at 60 cents a pound, fabricated and erected with its strength ratio between concrete and steel is about one to ten is also a bargain. Concrete is six cents a pound; steel is 60 cents a pound. So you use ten times as much concrete at one-tenth the price, and as Professor Tucker mentioned a minute ago, when you run out the numbers in most major cities and you look at the concrete and the form work versus the steel and the metal deck with the concrete, they both come out to be $6.00 to $8.00 per square foot. They're competitive. You can't get it any better than that, and so I don't see much revolution happening in the area of structural systems unless the new material's cost can be reduced.

We, on occasion, have ventured into the development of esoteric materials for structures, We usually end up getting very frustrated and disappointed with the result. About twelve years ago we developed a paper bridge for the international Paper Company. It was meant to be a television commercial, but we found the material to have fantastic potential. Paper is a marvelous material, and we thought it had fantastic applications for concrete formwork and disposable formwork. You can make it waterproof, you can make it fireproof, and it's stronger pound for pound than concrete. It's basically processed wood when you think about it. It has never caught on as a construction material. The paper industry never caught on to it, but there's no reason why paper in a honeycomb, cellular-type system could not be developed as a formwork system for concrete. It just hasn't happened to date.

We've found that most new developments in the area of materials occur in what I call adaptive use of off-the-shelf items. It's probably an area that should be looked at further. A few years ago we designed and engineered several superbay hangers for American Airlines in California. Each building held four 747s. We took an H.H. Robertson or Inland-Ryerson type cellular electrified deck for a typical office building floor and applied it to a hyperbolic paraboloid structure. We used simple spot welds. It worked marvelously. This 230-foot catilever structure had only about ten pounds of steel per square foot in it. We were supposed to build eight of them. We only built two, and no one has done another one since.

In order to achieve this innovative structure, we had to deviate from normal practice. The process was brought together. We were the engineers. None of the contractors wanted to analyze the erection schemes; so we analyzed the erection schemes. Nobody knew how to maintain the quality control on the part of the contractor; so we set up the contractor's quality control manual. We stuck our necks out relative to normal responsibilities and it worked.

There is a great tendency toward fragmention and diversity in our industry. I think the whole role of the designer and the constructor has to be redefined. There have been many recent conferences, papers and hearings about designers (architects and engineers) skirting their responsibilities relative to design of steel connections, for example.

There are hearings going on in Missouri right now to try and revoke a structural engineer's license for the Kansas City Hyatt collapse. The engineer is saying it was the contractor's responsibility. The contractor is saying it was the engineer's responsibility. When you go and look at the American Institute of Steel Construction (AISC) specification in depth, you find that it's really very confusing as to who is really responsible.

What has happened is, although engineers and architects have wanted to get more involved in the construction process, their insurance company, lawyer, ASCE, AIA, ACEC, and everybody else involved has said, "You shall not be involved in construction means and methods. You shall not be involved in erection sequences. Stay out of it. Don't use the word 'approved'. Don't get involved, and keep it fragmented."

Well, in spite of this approach for the last twenty years, there are still too many problems and too many lawsuits. I think what's happening is the ACEC, ASCE and AIA are starting to come back and say, "I think that the designers have to play a bigger role in the construction process." Further justification of more involvement is in the fact that one-third of the project cost relates to an interim financing cost. Designers should get closer to the construction process through their computers (CAD) and link the design to the construction by taking contract documents and converting them into mill orders and shop drawings (CAM) to bring the whole process together. That's really where the big savings can take place.

Here are a couple of examples. Turner Construction Co., on a $80 million Westin Hotel recently built in Boston, decided they were going to slip-form the concrete core of the project. No one had ever done it before in Boston. I told them I thought they were crazy because of the difficult local trade jurisdictions and strong unions in Boston. But they decided they were going to take a crack at it. They brought the unions into the picture early and made them part of the process.

Since Turner was involved as the construction manager early in the game, we, as designers, agreed to use a slip-formed core. We also agreed we would use a flying-form system, and we would design the precast facade so that it could be incorporated into the flying-form system. So when the building form went up, the precast pieces went up with it, and when they poured the floor, they inserted the windows, and in record time they had an enclosed building so that the other trades could come in and work on the remaining systems within an enclosed, heated environment.

Had we not worked together on the approach in the early stages, it would have been a much more conventional building, We got involved in the process and it paid off for the project.

Olympia & York, the developer of the World Financial Center at Battery Park City in New York, tried to apply what they do in Canada to New York. They deserve a lot of credit — they got halfway. What they did is interesting. They incorporated the material-handling systems that are needed during the construction into the basic design of the building. The elevator shafts are sized so that all materials go up and down inside the building, not on an exterior materials hoist.

For a conventional project, we never know in advance who the contractor will be. As a result, we don't bother to try to accommodate the design to facilitate materials handling to be facilitated. Do you know what the cost of a lift on the outside of a building is? With post-modernist design solutions, with setbacks when you get up to the sixtieth floor and you've got to get over 60 feet to reach the exterior wall (how do you get it from here to there?) it's a big problem!

So the recent tendency to have buildings with setback tops could swing us more to central materials-handling systems. It is obvious that construction managers and general contractors as well as designers have to be more involved in that total process. This will save time and money.

In summary, I think in the immediate future further impacts will be in the area of computer usage; integration of various building systems; the exterior walls and the structure; gradual acceptance of new materials; and a whole change in the delivery process. Big changes are going to result from these impacts.

The other obstacle is the impediments, which everybody has talked about; unions, special interest groups, codes, jurisdictions and, from a designer's side, fear of litigation. It's gotten to the point where most, if not all, of the United States' design industry is not innovating any more because of fear of litigation. It really doesn't pay to innovate any more, because the chance of getting nailed, in our litigious society, is almost predictable. There may not be too many attorneys in Japan, but there are too many attorneys and too much litigation, too many frivolous lawsuits against the practice of architects, engineers, medical doctors, etc., in the U.S. today. This aspect of our industry is hurting the advancement of, and innovation with, the American design and construction industry.

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