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Implications of WTC Attack on Concrete Research

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Introduction

The terrorist attacks on the World Trade Center and the Pentagon have changed the world as we knew it. Although there is clearly an immediate need for reconstruction of Lower Manhattan, it is too early to predict what all of the implications on the construction industry nationwide will be. Yet, the very real terrorist threats we have to learn to live with will have repercussions on the types of future construction as well as the materials used. And as is typically the case when design specifications undergo major changes, the main challenge to society will be to decide how to deal with existing buildings and structures. In other words, the design and construction of new facilities poses generally fewer problems than the retrofit of existing ones. This situation will present the concrete research community with new challenges, which are the topic of this article.

It is fairly safe to say that more progress has been made in the field of concrete technology during the last thirty years than during the first 150 years since Joseph Aspdin, the builder from Leeds, England, figured out how to make cement, which was named for its resemblance of the natural stone quarried in nearby Portland. It is even more true that none of this progress was made by people who walk through life “doing things the way we always did”. It was the entrepreneurs and risk takers who were responsible for these advances by deciding to try something else and to provide the necessary investments in research and development, with success far from being assured.

An illustrative example of this progress is the maximum compressive strength of commercially available concrete. In the 1970s, a 5000 psi mix would qualify as high strength concrete and would most likely be called for in prestressed applications. Nowadays, a mix would have to break at least at 7000 or 8000 psi to even qualify for that label, and a 18 ksi mix is no longer a spectacular novelty. Structures have already been built with ultra-high strength concrete, such as reactive powder concrete, with strengths exceeding 30 ksi.

This progress was made in spite of the fact that the construction industry is not particularly known for its inventiveness and eagerness to invest in research. On the contrary, it is probably the most conservative industry, and for a good reason. The structures we are erecting have to satisfy public safety requirements that are fairly unique. “Tried and true” is a concept meant to protect the public, and at the same time, the burden of proof is placed on the innovator as a formidable barrier against change. To introduce a new building material, for example, the innovator will have to convince the authorities, that it will be safe throughout the expected service life. Since a genuine track record is achievable only under realistic service conditions, we are caught in a Catch-22 situation: to place the new material into service, it has to have a track record. But we cannot obtain the track record, without first having the material placed into service. To escape this viscous cycle, we need both innovators and courageous authorities, willing to give change a chance. Although not sufficient, a healthy trust in research is certainly a necessary part of this and also justified because we do have the capabilities to simulate in the laboratory service life conditions, even though highly accelerated simulations are possible only with drastic simplifications of real life conditions.

The attack on the World Trade Center is an historic event with consequences affecting many different aspects of life. It has already prompted a national and international debate on whether or how we ought to continue erecting tall buildings. One outcome of this discussion will be a consensus on the kind of risks we as a society are willing to accept. It can be assumed that not many of us wish to live and work in fortresses designed to withstand a full aircraft impact. But the public debate that has just begun will have to focus on the types of loading conditions structural engineers should be considering on a routine basis that were not considered in the past and what further measures to reduce risk are economically sustainable.

Compared with these fundamental issues, the required changes in the construction industry's perception of research and innovation will possibly be less difficult to achieve. If we can convince the public that a new material or type of construction can buy a tangible increase in safety, the inherent resistance to change will be much easier to overcome.

If we wish to identify those subject areas that deserve the attention of researchers, it is useful to start asking the question: What would have been necessary to reduce or minimize the damage to the Twin Towers caused by the aircraft impact and subsequent explosion and fire? It is unrealistic at this point to suggest that the structures should have been able to withstand such an aircraft impact without major damage. However, in accordance with structural design principles followed for the last hundred plus years, it is appropriate to require that collapse should have been prevented and the damage be as localized as practically possible. The consequences would have been that all building occupants not in the immediately affected areas had the opportunity to safely evacuate the buildings, and that fire fighters were given a reasonable chance to extinguish the fires before the damage increased to the extent of endangering the integrity of the buildings.

To translate these requirements into recommendations for research, it is logical to consider the demands on the structural materials separately from structural design requirements. Emphasis shall be placed here on concrete materials research.

Fire Resistance

The most obvious need is the improvement of fire resistance of our construction materials. In this regard, concrete has been known to be inherently superior to structural steel, which requires costly measures of fire protection. If research efforts to develop new concrete mix designs with improved fire rating are successful, the benefits will apply to concrete and composite construction as well as to the fire proofing for steel construction.

A considerable body of knowledge is available on fire-resistant or refractory concrete [1,2]. In order to achieve further progress, we have the tools of modern materials scientists to engineer new materials to satisfy given specifications, within limits, of course. It is known that at high temperatures, both the free water and hydrated water are gradually turned into steam and driven out, which leads to considerable shrinkage. A low water content, already required for high-strength mixes, also increases the resistance to high temperature. But at the same time, the pore structure offers escape routes for the steam. Since high strength concretes are typically very dense, they lack this escape mechanism. Therefore, high strength mixes are known to fail explosively at elevated temperatures. One solution of this dilemma is the reinforcement of high-strength mixes with both steel and polypropylene fibers. The polypropylene fibers, thanks to their low melting point, will create a capillary structure, which serves to relieve the internal steam pressure [3].

In order to increase the fire resistance of a concrete material, one has to carefully balance its various components. The aggregate itself has to be resistant to high temperatures. The resistance of the cement matrix must be improved, typically by substituting high alumina cement for ordinary Portland cement. Also, it is important that aggregate and matrix have similar thermal expansion coefficients. Truly refractory concretes are characterized by ceramic bonds that form at elevated temperatures.

Considerable progress is possible by scientifically analyzing material behavior at elevated temperatures. Much is known about such behavior on the atomic and molecular levels. Comparably little is known in the concrete community about the comparable phenomena on the micro- and macroscopic levels, although in ceramic sciences a good body of knowledge is available [4]. Economic considerations pose an important challenge. There exist extremely heat-resistant materials, for example, the ceramic tiles that protect the space shuttles upon reentry into the atmosphere [5]. Theoretically, we could fireproof steel frames with such material, but the cost would be prohibitive. Concerted research efforts could transfer the knowledge of ceramics to cement composites and at the same time refine the manufacturing process in order to reduce cost.

The fire proofing of structural steel represents a particularly challenging topic for research. Here, basic materials science and production technology need to converge to arrive at more effective, yet economically feasible solutions, that include improved bond properties, so that the protective coating is not easily knocked off by blast or impact load.

Impact and Blast Resistance

Another area of concern is the development of materials that are suitable for impact and blast resistant structures. Here, fiber-reinforced concrete has become the material of choice in recent years [6,7]. Significant advances have been made to engineer either randomly distributed short fibers or continuous fiber mesh as well as the concrete mix such as to optimize the energy absorption capacity of the composite. High-performance fiber-reinforced cement composites are specially engineered to optimize this energy absorption capacity by forcing secondary cracking, which turns an originally brittle cement composite into a truly ductile material [8.9].

Most of the past research has concentrated on randomly distributed short fibers, with reinforcing percentages as high as 15% and more in systems known as slurry infiltrated fiber composites [10] or fiber-mat composites [11]. Such materials are extremely tough and well suited for a number of applications.

Fibers will undoubtedly be an important ingredient of modern cement composites. Their purpose will be to improve both the fire resistance and the energy absorption capacity of the material at reasonable cost. It is ironic that there exists a type of fiber that satisfies these requirements and in fact used to enjoy considerable popularity in the past - namely asbestos. The rise and fall of their popularity illustrates the importance of health concerns as well. Thus, the research community is challenged to find a suitable fiber to succeed asbestos that is environmentally benign, cost-effective, fire-resistant, and suitable for use in highly ductile fiber-reinforced cement composites. The solution will most likely be a mineral fiber, such as basalt. At Columbia University, an initial research program has evaluated the suitability of such fibers, which were manufactured using a process invented in Ukraine. A concerted research effort would be needed to determine the feasibility of basalt or other mineral fibers in satisfying the various performance requirements outlined above.

Less research has been done on cement composites utilizing continuous fiber mesh reinforcement. It is difficult, though, to draw the line between such composites and others known as ferrocement, which were developed long time ago [12]. But it is in order to revisit these systems and then to systematically engineer composites to achieve the mechanical and other properties as specified. As plain concrete is typically very brittle, the primary objectives are often an improvement of ductility and toughness or energy absorption capacity.

Whether the fibers are added as randomly distributed short fibers or continuous fiber mesh, it is important to note that the needed research should always proceed in tandem with the development of a suitable production technology so that the material can be economically mixed, placed, pumped or sprayed, consolidated and finished.

Other Research Areas

It is appropriate to mention a further design objective for the concrete researcher. Concrete suffers under the widely held perception of being ugly, based on the large number of structures that have been built without much regard to esthetics. But concrete does not need to be ugly, since the requirements for architectural surface treatments are not difficult to achieve [13]. The concrete industry is well advised to pay closer attention than it did in the past to esthetic aspects, which can easily translate into significant economical savings. By eliminating costly paint or cladding jobs, a well-designed mix with architectural surface treatment may very well turn out to be the most competitive solution.

Another area in which research can improve the economy of concrete is the proper use of recycled materials. The “green building” movement has taken off, and demands for sustainable development are likely to determine to a large extent how well concrete will fare in the future compared with other materials. In New York, there exist already laws and regulations that offer tax incentives for recycled material content [14,15]. At Columbia University, a widely publicized research program has resulted in the development of concrete products using recycled glass as aggregate with spectacular results [16,17]. There are other possibilities to improve the environmental friendliness of concrete. These may consist of replacing part or all of the Portland cement by fly ash or granulated blast furnace slag using suitable activators, as well as beneficiating various waste materials to become suitable ingredients in concrete [18].

Conclusions

The collapse of the Twin Towers has shown that there is a need to improve structural design concepts for improved life safety of tall buildings. For example, the progressive collapse of multistory buildings has been an issue in the design community ever since the accident of the Ronan Point Apartments in 1968 [19]. But even long before then, structural engineers have recognized the advantages of continuous, “redundant”, structural systems, which offer alternate load paths in the case of local distress or failure. Also, structural and other measures can be taken to increase the blast resistance of structures. As for design approaches, there are the obvious challenges that have already been addressed, for example, in conjunction with the State Department’s program to harden US embassies abroad. The most important advances to be expected in the near future, however, will take place in the field of concrete materials research

Some of the expected advances in terms of enhanced safety will result in higher costs, but not necessarily so. The investments in the necessary research and development costs are relatively modest, all things considered. Thus, as an industry, we are well advised to pay more attention to the new materials and structural schemes that research may make available and then let society at large decide the questions of cost effectiveness.

The advances in modern technology have been due almost entirely to research. If the construction industry in general and the concrete industry in particular are to make progress comparable to those achieved in other industries, we have to recognize the importance of research. And we will have to exert the will to put all the talent to work that can be found right among us.

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