Protective Structures in the 21st Century

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ABSTRACT

The paper includes the description of the author's vision on the protective structures in the 21st century.

The structures discussed are civilian (not military) and their protection is against attacks by weapons, explosive devices, chemical and biological agents and terrorists.

The paper is written from the architect and structural designers view of the structures and is based on the author's extensive practical experience in the design of protective structures, as well as on his knowledge on the research and developments of future weapons, on one hand, and on future protective design methodologies, on the other hand.

1. INTRODUCTION

In the first 20 centuries, humanity on Earth has a history of continuous conflicts and fighting, which led to the building of numerous types of protective structures, such as the fortified medieval castles, walled and protected cities, civil defence shelters, underground protected installations and many more.

In the 20th century, the two world wars and the numerous local conflicts have led to the design and construction of numerous protective structures of all types, which, in general terms, have provided protection to the civilian population and important installations.

So, what can we expect in the 21st century? May be, hopefully, there will be peace on Earth and there will be no threats on people and no need for protective structures. Looks like "wishful thinking"?! Unfortunately, it is more likely that local conflicts will continue and that there will be an increased threat from local as well as international terrorism.

Therefore, the author foresees that at least in the next decades there will be an international activity in designing and building new protective structures, as well as retrofitting existing structures to resist the effects of various types of attacks.

2. HOW SAFE ARE PEOPLE IN OUR BUILDINGS?

Since leaving the prehistoric caves for habitats "in the open", the main purpose of the structures designers was to provide to people protection against climatic factors such as rain, snow, wind, heat and cold, etc. We can confidently say that now our buildings are effectively providing this "climatic protection".

In the 20th century we have added to our structures the capability to withstand much better severe natural hazards such as earthquakes, storms, flooding, etc. We can say that now our buildings provide much better protection against severe natural hazards.

With the introduction of electrical and mechanical systems in our buildings, the threats of fire, gas explosions, etc. increased. Unfortunately, the safety of our buildings against fire is still not optimal and we should invest more in protecting the people in the buildings from this risk.

What we found lately is that normal unhardened buildings do not provide adequate protection to people from weapons and explosive effects. Moreover, local damage from explosive effects induced partial and even total progressive structural collapse and the hazard to people in the building increased considerably. In some cases, the buildings themselves have become a most destructive weapon used by terrorists seeking to induce maximal injuries and property damage.

We have also witnessed extensive injuries to people in buildings from glass fragments, debris and falling/flying objects following terrorist attacks using explosive charges.

We, unfortunately, have to say that people are not safe at all in normal buildings attacked by weapons and explosives. Many times people would be safer outside the buildings than inside!

This is the reason for implementing in our structures adequate cost effective protective measures, including hardening structural and architectural materials and methodologies, and these are the protective structures we address here.

3. NORMAL STRUCTURES IN THE 21st CENTURY

So, what type of "normal" structures do we envisage in the 21st century?

Due to the growing population, the increased urban areas, the diminishing land availability and other social-demographical factors, we foresee that the future buildings in urban areas will be taller, bigger, closer one to another and generally more "crowded".

From the architectural-structural design aspects, buildings will be more slender, more "light", more "transparent", and generally more "daring" and challenging the nature's constraints, especially gravity and ground and climatic conditions.

In these future buildings, without the addition of protective measures, people will be exposed to extreme hazards from weapons, explosive devices and terrorist attacks!

4. THE THREATS TO PEOPLE IN THE 21st CENTURY BUILDINGS

We can only assume and "guess" what will be the threats to people in the 21st century from war, local conflicts and terrorist attacks. Generally, we can expect the threats in the 21st century to include all the present threats, mostly by conventional weapons and explosive devices, but also future unconventional threats such as by chemical and biological agents, nuclear explosion effects and any other futuristic weaponry. We can also expect “surprise” attacks by terrorists using “unthinkable” means of destruction (and, unfortunately, the evil has no limits!).

In addition to the direct effects of the above mentioned threats, people inside buildings will be at increased risk from the buildings components themselves, including progressive structural collapse.

We are describing here a grim and dangerous scenario for humanity in the 21st century - this is the future we are providing for our children and grandchildren? How did we get to this near- apocalypse? Because we wanted progress and freedom and a better life?

There may be those who would say that we are too pessimistic and that the future threats are not going to materialize. We sincerely hope that they will be right. However, if even part of the future envisaged threats will materialize, we have to design our buildings with protective measures to minimize the possible catastrophic attacks consequences.

5. PROTECTIVE CIVIL DEFENSE STRUCTURES IN THE 21st CENTURY

Presently, civil defence shelters for people in cases of emergency are built in many countries worldwide. The shelters are built for various threats and levels of protection and are designed for the local rescue procedures.

We foresee that in the 21st century we will continue to design and build civil defence shelters for the population in cases of emergency for local envisaged threats, levels of protection and rescue procedures.

These civil defence shelters will be of several types:

a. Family shelters in homes or in apartments.
b. Common shelters in buildings basements or between buildings.
c. Dual purpose shelters in public buildings.
d. Public shelters in underground installations.

Generally, the civil defence shelters will be designed for the cases where there will be enough warning and people will have the time to reach the shelters. For situations with short warning times or no warning time at all (such as in cases of suicidal terrorists attacks, for example) people in buildings should be protected differently - for example by close-by protected spaces or by hardened building envelopes.

It is very important to take into consideration the need to provide shelters in existing structures and the design of the shelters to allow easy future upgrading, if needed.

The use of rapid-erectable “makeshift” shelters in emergencies should also be considered.

6. PROTECTION OF STRUCTURES IN THE 21st CENTURY AGAINST LONG RANGE ATTACKS

Long range attacks - when weapons are activated at distances of kilometres from our structures - can include low, medium or large scale weapons.

Low scale weapons include mortars, artillery shells, rocket-propelled projectiles such as Katiusha rockets, etc.

The effects of the above weapons on structures are relatively low blast loadings and fragmentation for near misses and local damage for direct hits.

The protective measures for this type of low scale weapons attacks are:

a. External shielding elements such as blast and fragment resistant protective walls surrounding the structure, protective shielding elements in front of windows, etc.
b. Roof protection elements such as additional steel or reinforced concrete or other blast and fragment resistant materials installed at a distance from the roof.
c. Use of blast and fragment resistant materials in the building envelope - the external walls and the roof.
d. Use of blast resistant windows in the external walls.
e. Building of protected internal areas.

Medium scale weapons include air-to-ground rockets, air bombs, small ground-to-ground missiles, etc.

The effects of the above weapons on structures are relatively large blast loadings and fragmentation for near misses and extensive local damage for direct hits.

The protective measures for near miss attacks of medium scale weapons are similar to those mentioned above, but stronger.

The protective measures to provide full protection for direct hits of medium scale weapons are not applicable to “normal” structures. Protective structures to withstand such direct hits include special designs such as protective layers, earth cover and shielding, external “sacrificial” elements, etc.

To minimize the damages from direct hits, we can implement the protective measures for near misses and add strengthening measures to prevent total structural collapse (as discussed later).

Large scale weapons include big ground-to-ground missiles, etc.

The effects of the above weapons on structures are large blast loadings for near misses and extensive damage for direct hits.

The protective measures for near miss attacks of large scale weapons are similar to those mentioned above, but much stronger.

The protective measures to provide full protection for direct hits of large scale weapons are not applicable to “normal” structures. Protective structures to withstand such direct hits are special designs such as underground structures with protective layers, structures in rock caverns, etc.

7. PROTECTION OF STRUCTURES IN THE 21st CENTURY AGAINST SHORT RANGE ATTACKS

Short range attacks - when weapons are activated at distances of hundreds down to several meters from our structures - can include shooting of small arms: rifles, machine guns, etc. mortars, rocket-propelled projectiles such as Katiusha rockets, antitank projectiles such as RPG, etc.

The main effects of the above weapons on structures are relatively low blast loadings and fragmentation for near misses and local damage for direct hits.

The protective measures for near miss attacks of short range weapons are similar to those mentioned above for near miss of low scale long range weapons.

The protective measures for direct hits of short range weapons are designed to withstand the bullets penetration and to induce the explosion of the rockets on the building envelope or on external shielding materials.

8. PROTECTION OF STRUCTURES IN THE 21st CENTURY AGAINST TERRORIST ATTACKS

Terrorist attacks on structures are mainly by placing explosive devices or by explosives activated by suicidal terrorists.

The terrorists will try to place the explosive devices inside the structure in such locations that the damage to the structure, and the related number of injuries, will be as high as possible. They will also try to use the most devastating explosive charges, incendiary devices, devices including metal shrapnel, poisonous gases, etc., as their evil minds can think of.

We must now state that the protection of people inside structures against terrorist attacks include several types of countermeasures:

a. Preventing the access inside the building, by perimeter protective barriers, anti intrusion and alarm systems, access control measures, electronic surveillance equipment, and security guards.
b. Preventing the placing of explosive charges and damaging devices close to sensitive structural elements and internal areas by electronic surveillance equipment, security guards and adequate protective shields and barriers.
c. Implementing hardening measures to minimize the structural damage in case an explosion does occur.

The hardening measures should be designed in several "protective layers", providing resistance to the terrorist attacks effects and ensuring that failure of one protective barrier will not have catastrophic consequences, as the other barriers will be still functional.

9. HARDENING "PROTECTIVE LAYERS" FOR STRUCTURES

The first hardening "protective layer" is on the perimeter of the structure area, on the "fence line".

The perimeter barrier should provide the first "line of protection", for example:

a. Preventing terrorist forced entry, including vehicle crashing through.
b. Shielding against shooting, thrown stones, incendiary devices, hand grenades, small explosive charges, etc.

c. Mitigating the blast from larger explosive charges such as car bombs.

The second hardening "protective layer" is on the envelope of the structure area, on the external walls and roofs.

The structure envelope barrier should provide:

a. Further prevention of terrorist forced entry.
b. Shielding against shooting, thrown stones, incendiary devices, hand grenades, small explosive charges, etc.
c. Shielding against fragmentation from near misses of shells, air bombs and other fragment-inducing weapons or terrorist devices.
d. Mitigation of the blast reaching the structure from larger explosive charges.
e. Shielding of main structural elements, such as columns on ground and lower floors, from explosive devices placed in contact.

The third hardening "protective layer" is on the envelope of the internal areas inside the structure.

The internal barrier should provide:

a. Further prevention of terrorist forced entry.
b. Shielding against shooting, incendiary devices, hand grenades, small explosive charges, etc.
c. Shielding against fragmentation from near misses of shells, air bombs and other fragment-inducing weapons or terrorist devices.
d. Mitigation of the blast reaching the internal areas inside the structure from larger explosive charges.
e. Shielding of main structural elements, such as columns, from explosive devices placed in contact.
f. Mitigation of the blast induced by explosives detonating inside the structure.

Reading the above it may seem that implementing hardening measures in structures would make them bunker-like. This should not be so! The architects and the structural engineers can include the protective design measures so that the functional as well as the aesthetic aspects will not be "disturbed". All it takes is first to be ready "to make an effort", then to use innovative methodologies and finally to "think creatively".

It is also very important to use protective materials and methodologies that will provide the best "human-friendly" environment for the people inside the structure and the protected areas. The architects should also take into consideration psychological factors such as people's behaviour under severe stress. As expected in emergency situations.

Finally, the designers should provide adequate emergency exit and rescue means and procedures as well as taking into consideration the quick repairs to damaged structural elements.

10. PREVENTING PROGRESSIVE STRUCTURAL COLLAPSE

The main effort of the designers should be to prevent structural progressive collapse in case of an attack, due to the catastrophic consequences which may culminate in very large number of injured people in and around the collapsing structure.

Unfortunately, structural collapse of the modern unhardened structures which will be built in the 21st century can be achieved quite easily by skilled and determined attackers, especially by suicidal terrorists (and surely we will not detail here how it can be done!).

In order to prevent structural collapse the designers should analyze the possible consequences of severe local damage to main structural elements from effects of weapons, explosive charges and other destructive devices.

The structural protective design principle should be that severe local damage to main structural elements such as columns, beams, walls, shafts, etc. (which cannot be totally prevented by the various security measures) should not induce progressive structural collapse and definitely not the total collapse of the whole building.

Some of the protective measures adequate to increase the resistance of the structure to progressive collapse are:

a. Prevention of progressive collapse in case of severe damage to a major structural element.
b. Prevention of structural failure for reverse loadings, acting in the opposite direction (for example upward loading for intermediate slabs).
c. Increased strength of structural elements connections, especially slabs to columns and columns to beams.
d. Increased strength of structural elements in areas most vulnerable to explosion effects, such as on ground and lower floors, columns in basement parking areas, etc.
e. Use of ductile materials for structural elements and design of connections to provide ductile response.
f. Shielding of the main structural elements by shock absorbing materials and/or elements.

In the 21st century more “creative solutions” for the protective design to prevent progressive structural design will surely be developed.

Some of the author’s concepts for improved column protective design (some of which have already been applied) are:

a. Shielding columns by energy absorbing composite section shields built with an air gap around the columns.
b. Shielding columns in sensitive areas by energy absorbing and architecturally/functionally accepted walls/partitions.
c. Designing columns in sensitive areas to be connected as much as possible by even light partition walls, “hiding” them as much as possible.
d. Designing columns in sensitive areas as part of strong walls, reducing their sensitivity to local failure.

e. Designing columns in sensitive areas with inner strengthening means as well as outer strengthening casings.

f. Designing columns to be part of an overall frame structure with the adjacent beams and slabs by using adequately designed ductile and bending moment carrying connections.

g. Designing columns to prevent buckling in case of damage to adjacent horizontal supports such as beams, slabs, etc.

Protective design concepts for the general structural scheme, proposed by the author (some of which have already been applied) are:

a. Providing as many as possible “hardened staircases” as part of the structural frame with adequately designed connections to the adjacent slabs, providing increased overall resistance to progressive structural collapse. These staircases should also provide fire protection and easy emergency exit paths for people as well as easy access paths for fire fighting and rescue teams.

b. Designing slabs to remain ”hanging” from staircases or other walls in case of local collapse, preventing their collapse to the bottom of the building. This can be achieved by adequately designed slab supports.

c. Designing special “debris load bearing” elements at various locations in the structural frame, capable of not collapsing under debris of collapsed floors above them and preventing total structural collapse.

d. Designing the structural frame not to collapse in case of damaged local areas by building it as a “space lattice”, where local “holes” will still not induce progressive collapse.

e. Designing the structural frame in such a way that in case of damaged local areas the rest of the structure will remain “hanging” on strong elements above the damaged areas.

f. Designing the structural frame in such a way that in case of damaged local areas the structure above them will collapse “sidewise” in a pre-designed direction and will not load the bottom undamaged structure.

The extremely important task of designing structures so that progressive collapse will be prevented is not just the responsibility of the structural engineers but also of the architects, who should contribute to the “creative thinking” and should strive to optimally implement the required protective design features in the building design.

11. THE USE OF BLAST RESISTANT WINDOWS AND CURTAIN WALLS

The modern buildings in the 21st century will probably include large glazed areas on their elevations such as windows and curtain walls.
Unfortunately, this may be harmful to the people inside the building who can be injured by the flying glass debris. The extent of the injuries can be great due to the very low resistance of normal glazed elements to blast loadings.

Therefore, to minimize injuries from glazing fragments, blast resistant windows and curtain walls should be preferred.

Blast resistant windows and curtain walls are available and have been already successfully implemented in various structures. To increase the blast mitigation and reduce the level of injuries, various “energy-absorbing catching” systems (bars, cables, meshes, etc.) installed behind the glazed elements have been developed and are already being implemented.

External shielding elements of various types also contribute to the blast mitigation.

In the near future we foresee the development of better, lighter, nicer and cheaper blast resistant glazed elements and their increased use to provide adequate protection to the people inside the buildings from blast and explosive effects.

12. IMPROVED MATERIALS FOR PROTECTIVE STRUCTURES

In the 21st century we foresee that the extensive research and development efforts will lead to finding better materials to be used in protective structures, which will contribute to implementing more cost efficient protective measures in our structures.

Such improved materials should provide increased protection against the future threats and be more efficient in withstanding blast, fragmentation, impact, penetration, fire and other effects of explosions and terrorist attacks.

The following materials are probably going to be increasingly used in the protective structures of the 21st century:

a. Improved concrete materials: high strength concrete, concrete with fibers of various types, non-brittle concrete, concrete with strong aggregates, light concrete, concrete with plastic-based components, etc.
b. Concrete with protective covers: composite materials, woven liners of various types, plastic and metal covers, etc.
c. Confined concrete: concrete confined between various plates.
d. Concrete filled blocks of various types.
e. “Soft-hardening” materials: high energy absorbing elements providing increased hardening while being softer and more ductile.
f. Composite steel and concrete elements of various types.
g. Layered materials with various materials and layer configurations.
h. Protective glazing materials, with increased blast and impact resistance.

For underground and soil covered structures we foresee in the 21st century the increased use of “reinforced earth” materials, making use of the soil in resisting the ground shock loadings.

And who knows, maybe later in the 21st century we will find the technologies to protect our structures by external domes, as described in many science fiction books!?

13. PROTECTIVE RETROFIT OF EXISTING STRUCTURES

The protective design principles described above for new structures apply also for the strengthening of existing structures to enhance their resistance to the effects of weapons and terrorist attacks. However, the actual implementation of these principles in existing structures is somewhat more difficult.

A special challenge for the structural engineers is the strengthening of the existing structure to prevent progressive collapse. However, it is feasible and it can be achieved with reasonable costs. We foresee that in the 21st century many innovative solutions will be found and implemented to prevent progressive collapse of existing structures due to weapons, explosives and terrorist attacks.

Another challenge, mainly to the architects, is to strengthen the existing openings in the building's envelope, including windows and other glazed elements, as well as curtain walls, in existing buildings, to reduce the hazards to people inside the building from flying glass fragments, debris, etc.

We foresee that in the 21st century many innovative solutions will be found and implemented to mitigate the hazards from fragments of glazed elements and debris of non-structural components in existing structures due to weapons, explosives and terrorist attacks.

Also challenging is the strengthening of the existing non-structural walls and claddings on the existing building elevations to mitigate the hazards from flying debris.

Various protective retrofit methodologies have been extensively tested and feasible solutions are already available, mainly by different additional layers applied on the back of the existing walls.

We foresee that in the 21st century many innovative solutions will be found and implemented to mitigate the hazards from debris of non-structural masonry walls and light partitions/claddings in existing structures due to weapons, explosives and terrorist attacks.

14. PROTECTIVE DESIGN SPECIFICATIONS

Although many protective design principles and examples have been presented in latest symposia and conferences, there is presently no protective design manual or set of specifications internationally acknowledged and accepted for designing civilian structures to withstand weapons and explosion effects as well as terrorist attacks.

This lead to the need to engage specialized professionals with knowledge and experience in the design of protective structures - in the United States they are called blast consultants. In Israel, these specialists are referred to as protection/hardening consultants - the author is recognized as such - and their expertise, which is normally based on vast experience with military and civil defence structures, is applied, very effectively, in the protective design of civilian structures.

Still, most of the actual protective design procedures, even for civilian structures, are classified, due to the owner/client requirement not to disclose the details of the defined threats and the protective measures.

It seems that, at least in the beginning of the 21st century, this status will continue and the expertise of protective design will be provided by specialized professionals on a project-to-project basis.

However, it is the author's opinion that the principles of protective design and examples of protected civilian structures should be made available to all interested, with the restriction of not disclosing the threats definition and the protective measures details, which are client confidential.

15. COST EFFECTIVENESS OF THE PROTECTIVE MEASURES

There is a certain reluctance of the building owners to implement protective design measures due to the additional cost involved.

At least, statements made before that protecting a structure from explosion effects and terrorist attacks is not feasible have been proven unsubstantiated.

The cost benefit of various protective design features should be based on a risk/cost assessment analysis, where the expected risks, expressed in injuries to people and/or loss of property are plotted versus the cost of the protective measures.

It was found, in many projects worldwide, that an optimal range of implementing protective measures for the highest cost benefit can be defined, by applying the procedures described in SEPHRA (SEcurity, Protection and Hardening Risk Analysis), developed by the author.

The accuracy of the most cost effective protective measures is largely based on the adequate quantification of the risk levels as function of the characteristics of the protective measures, which is achieved by using the practical experience gained from full scale explosive tests and from the analysis of observed damages to structures from real attacks.

The main conclusions from using SEPHRA in many projects are:

- not implementing any protective measures costs no money, but the risks remain high and unacceptable in most cases.

- achieving total protection - no risk whatsoever - is impossible and nearing it is very costly.

- designing protective measures to be implemented in stages according to funds availability, until reaching the optimum range, is a widespread practice.

- implementing some protective measures is far more efficient than doing nothing.

We foresee that in the 21st century the optimal protective measures will be defined by using risk/cost analysis such as SEPHRA.

16. PROTECTION OF STRUCTURES IN THE 21st CENTURY AGAINST CHEMICAL AND BIOLOGICAL AGENTS ATTACKS

The issue is really to protect the people inside the structures from the atrocious effects of chemical and biological agents.

The great hazard to people inside structures is from agents propagating through the air and affecting the respiratory organs.

The basic protection of people against such chemical and biological agents is by using protective masks (such as those provided to all the people in Israel by the Home Front Command). Additional protection for the whole body against "skin attacking" agents is provided by protective clothing.

Still, the above personal protective measures can be enhanced by additional "collective protective measures" such as adequately airtight sealed areas inside the building. People warring masks and staying in sealed areas can be protected for a few hours against chemical and biological agents. Such internal protected spaces are presently being built in every building in Israel.

To allow people to stay in the protected spaces longer than a few hours additional air purification systems should be installed. Such systems are in use worldwide.

Sealing internal areas in existing buildings is also effective to provide protection to people from chemical and biological agents.

17. PROTECTION OF STRUCTURES IN THE 21st CENTURY AGAINST NUCLEAR ATTACKS

In the 20th century, during the Cold War period, the treat of nuclear attacks has led to the construction of numerous nuclear shelters of all types. We can mention as examples the nuclear shelters built in many structures in Switzerland and the fallout shelters built in the United States.

In the 21st century we foresee that several countries will still feel threatened by nuclear attacks and will provide certain protection to the population.

However, we do not see any special developments in the design of protective structures against nuclear attacks and, therefore, we think that future protected structures against nuclear attacks will be designed based on the experience gained with similar structures in the 20th century.

18. PROTECTION OF STRUCTURES IN THE 21st CENTURY AGAINST HAZARDS FROM NEARBY INSTALLATIONS

In the 21st century, people in buildings located near military and industrial installations may be at risk from the possible explosive effects and/or the hazardous materials which may be released due to various attacks.

For example, people in buildings located near military installations may be at risk from the possible explosive effects of ammunition which may explode following war, terrorist or sabotage attacks.

Explosive effects of fuel, liquid gas and other such materials stored in aboveground tanks may also be hazardous to people in nearby structures.

Serious hazards can be induced by the release of poisonous materials from various industrial installations damaged by different types of attack.

Extremely serious hazards can be induced by the release of radioactive materials from nuclear power plants, laboratories and other similar installations following various attacks.

The above described hazards can obviously occur as result of accidents of all kinds (God forbid!).

We therefore foresee that in the 21st century structures located in the vicinity of installations containing explosive and hazardous materials will be designed to include adequate protection measures for the people.

Obviously, protective measures mitigating the damaging effects should be implemented in the above described hazardous installations themselves!

19. PROTECTION OF STRUCTURES IN THE 21st CENTURY CONTAINING IMPORTANT SENSITIVE EQUIPMENT

With the increased development of high-tech modern equipment installed in the structures of the 21st century we can expect the sensitive equipment components to be at risk from various effects of war, terrorist and sabotage attacks.

Structures including important sensitive equipment are, for example:

- computer centres

- control centres

- communication facilities

- broadcasting installations

- banking and commerce centres

- information processing and storage installations

- research facilities

In view of the possible attacks effects, resulting in extensive direct damages to the important sensitive equipment and considerable indirect damages resulting from the incapacitation of the equipment, we foresee that the 21st century structures containing important sensitive equipment will be designed to include adequate protection measures.

20. PROTECTION OF STRUCTURES IN THE 21st CENTURY CONTAINING UTILITIES EQUIPMENT AND SYSTEMS

With the increased development and use of various types of utilities serving the people in the structures of the 21st century we can expect the sensitive equipment components to be at risk from various effects of war, terrorist and sabotage attacks.

Structures including important sensitive utilities equipment are, for example:

- power plants

- electrical power distribution stations

- transformer facilities

- water supply installations

- gas supply installations

- communications installations

In view of the possible attacks effects, resulting in extensive direct damages to the important sensitive equipment and considerable indirect damages resulting from the incapacitation of the equipment, we foresee that the 21st century structures containing important sensitive utilities equipment will be designed to include adequate protection measures.

Protective measures will also be implemented at sensitive locations along the utilities lines to prevent extensive damage to the systems functioning.

21. PROTECTION OF TRANSPORT STRUCTURES AND FACILITIES IN THE 21st CENTURY

We foresee that in the 21st century protective measures will be implemented in various types of transport structures and facilities, to provide protection for the people using them and to ensure their undisturbed functioning.

Such transportation structures and facilities are, for example:

- airport structures and facilities

- railways structures and facilities

- bus stations

- port and harbour facilities

- bridges and tunnels

22. PROTECTION OF SPECIAL STRUCTURES IN THE 21st CENTURY

We foresee that in the 21st century protective measures will be implemented in special structures.

Such special structures of national and international importance are, for example:

- museums including items of special value.

- important monuments.

- special historic structures.

23. SUMMARY

Like with all threat-protection situations, the more we will improve the protection the higher the threat may be in the future ; it seems that this process of cause-effect-cause-effect-and so on will be with us, designers of structures, in the near future and we have to be ready and capable to do our best and provide to the building owners the most cost effective and optimal protective design solutions for the duration of the structure's life. Good luck to us all!

24. ACKNOLEDGEMENT

I would like to acknowledge, again, the contribution of Mrs. Micaela Eytan, specialist protective design architect, my partner and spouse, in working together with me during all our professional life and leading to the implementation of the protective measures in the structures design with the least disturbance to their functional and aesthetic performances.

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