Monday, 20th February to Thursday, 2nd March 2006

ICTA Workshop ~ Saudi Arabia Ministry of Social Affairs

World Trade Centre Complex, New York  Tuesday Morning, 11th September, 2001

USA NIST NCSTAR 1 - Final Report on WTC 1 & 2 Tower Collapses

Fire Engineering Practice After 9-11

Dedicated WebPage

http://www.fireox-international.com/fire/structdesfire.htm

Introduction

On 11th September 2001 at the World Trade Center Complex in New York, a catastrophic failure in common practices and procedures was exposed :

- **Architectural** ;
- **Conventional ('Ambient') Engineering & Fire Engineering** ;
- **Building Management** ;
- **Emergency Services** ;
- **Control Organizations Having Authority / Jurisdiction** ;
- **Fire Safety Objectives in Building Codes / Regulations & Standards** ;

The **International Fire Engineering Community** must now begin to understand 'real' buildings, which comprise structure and fabric (i.e. non-structure) in an architectural relationship, and the 'real' people who use them. A renewed and special emphasis must, therefore, be placed on .....

Structural Fire Engineering ..... max. credible fire scenario

Protection of People ..... (max. credible user scenario)

Building Codes & Standards After 9-11

'Cost Effectiveness' has, in the past, seriously compromised the health of building users and the safety of firefighters/rescue teams.
Once vested interests get involved, it may take another 5-7 years (from 2006) before these codes, standards and practices are satisfactorily revised, and properly implemented.

Future Liability of Building Designers

Structural Design for Fire, and Fire Engineering Design generally, must improve dramatically. It must be shown, in Building Designs commenced after 2001-09-11, that 'Progressive Collapse in Fire' & 'Disproportionate Damage' have been adequately considered ..... and will be prevented.

USA NIST NCSTAR 1 - September 2005

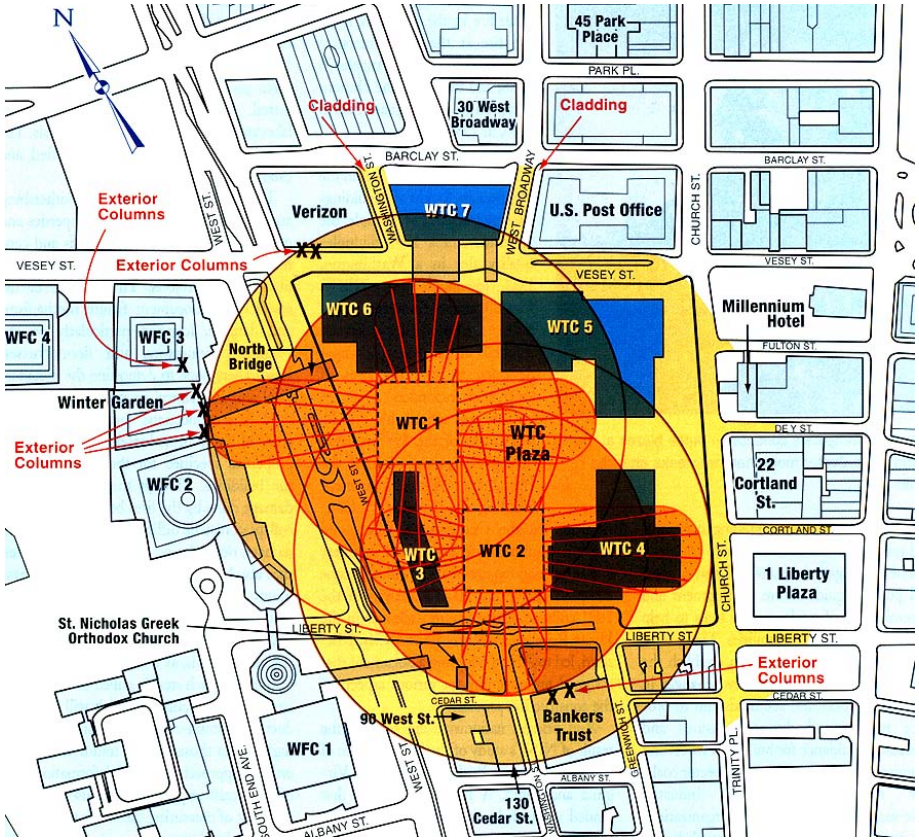
Federal Building & Fire Safety Investigation of the World Trade Center Disaster

Final Report of the National Construction Safety Team on the Collapses of the World Trade Center Towers

[WTC 1 & WTC 2]

On 26th October 2005 ..... Presented to the
Committee on Science
United States Congress, House of Representatives

By William Jeffrey, Director
National Institute of Standards and Technology (NIST)
Technology Administration
United States Department of Commerce



NFPA Journal - October 2002

Plan Drawing of the World Trade Center Complex

9-11 Immediate WTC 1 & WTC 2 Collapse Damage

USA NIST NCSTAR 1 - Final Report on WTC 1 & 2 Collapses

NIST's Recommendations for Improving the Safety of Buildings, Occupants & Emergency Responders

- **NIST believes** that these recommendations are both **realistic** and **achievable** within a reasonable period of time and that their implementation would make buildings safer for occupants and emergency responders in future emergencies.
- **NIST strongly urges** that **immediate and serious consideration** be given to these recommendations by the **building and fire safety communities** - especially designers, owners, developers, codes and standards development organizations, regulators, fire safety professionals, and emergency responders.
- **NIST also strongly urges** building owners and public officials to (1) **evaluate the safety implications** of these recommendations to their existing inventory of buildings, and (2) **take the steps necessary to mitigate** any unwarranted risks without waiting for changes to occur in codes, standards and practices.

NIST Recommendations - 30 in 8 Groups

[Chapter 9 (Pages 201 - 230)]

Group 1 - Recommendations 1, 2, 3

Increased structural integrity, including methods for preventing conditions that could result in **progressive collapse** (when a building or a significant portion of a building collapses due to disproportionate spread of an initial local failure), standardizing the estimation of **wind loads** that frequently govern the design of tall buildings, and enhancing the **stability of tall buildings**.

Group 2 - Recommendations 4, 5, 6, 7

Enhanced fire endurance of structures, including the technical basis for determining **construction classification** and **fire resistance ratings**, improvements to the technical basis for **standard fire resistance testing** methods, adoption of the **'structural frame' approach** to fire resistance ratings, and in-service performance requirements and conformance assessment criteria for **spray-applied fire-resistive materials**.

Group 3 - Recommendations 8, 9, 10, 11

New methods for designing structures to resist fires, including the objective of **burnout without collapse**, the development of **performance-based methods** as an alternative to current prescriptive design methods, the development and evaluation of **new fire-resistive coating materials and technologies**, evaluation of the fire performance of conventional and high-performance structural materials, and **elimination of technical and standard barriers** to the introduction of new materials and technologies.

Group 4 - Recommendations 12, 13, 14, 15

Improved **active fire protection**, including the design, performance, **reliability**, and **redundancy** of sprinklers, standpipes/hoses, fire alarms, and smoke management systems.

[Footnote 17. While there were unique aspects to the design of the WTC Towers and the terrorist attacks of 11th September 2001 ..... the design, construction, operation, and maintenance of the WTC Towers - and the emergency response to the WTC Towers - were based on procedures and practices that were commonly used for normal conditions.]

Group 5 - Recommendations 16, 17, 18, 19, 20

Improved building evacuation, including system designs that facilitate safe and rapid egress, methods for ensuring clear and timely **emergency communications** to occupants, better **occupant preparedness** for evacuation during emergencies, and incorporation of appropriate **egress technologies**.

Group 6 - Recommendations 21, 22, 23, 24

Improved **emergency response**, including better access to the buildings and better operations, **emergency communications**, and **command and control** in large-scale emergencies.

Group 7 - Recommendations 25, 26, 27, 28

Improved **procedures and practices**, including encouraging **code compliance by non-governmental and quasi-governmental entities**, adoption and application of egress requirements in available code provisions for **existing buildings**, and retention and availability of **building documents** over the life of a building.

Group 8 - Recommendations 29, 30

Education and training programmes for fire protection engineers, structural engineers, architects, and building regulatory and fire service personnel.

Presented in Matrix Format on Pages 224 & 225

Please read the Report !

In Our Opinion ..... There is a surprising strength and directness of language in the Recommendations of the NIST WTC 1 & 2 Final Report. And while older minds still remember the 3 R's of a Good Education, these Recommendations will also be remembered for their 3 R's :

Reality - Reliability - Redundancy.

- The Report raises fundamental questions about inadequate **Fire Engineering Practice** - not just in the USA, but internationally.
- The **Professional Fire Engineer** must in future act as a full member of an Integrated Multi-Disciplinary Building Design Team.
- The Report does not yet succeed in distinguishing between the **structural concepts** of 'progressive collapse in fire' and 'disproportionate damage'.
- In its treatment of 'disability' and **'people with activity limitations'**, the Report does not go far enough, and is seriously flawed.

Buildings Must Remain Structurally Stable :

- **while people are waiting in 'Areas of Rescue Assistance'**
- **until all of these people can be rescued by firefighters and can reach a 'Place of Safety'**

THIS is EsCaPe ~ NOT EVACUATION !!

Evacuate a Fire Building

To withdraw, or cause to withdraw, all users from a fire building, in planned and orderly phased movements, to a 'place of safety'.

In large-scale emergencies, it will be necessary to evacuate the fire building and adjacent buildings - in just one phase (??), and in the shortest practicable time - to 'places of safety'.

Skill

The ability of a person - resulting from training and regular practice - to carry out complex, well-organized patterns of behaviour efficiently and adaptively, in order to achieve some end or goal.

Evacuation Route Design Must Be Improved :

- min. 'Clear Width' required - to facilitate assisted building user evacuation and contraflow for firefighter access
- max. gradient for safety - with no projecting nosings, etc.
- attach an 'Area of Rescue Assistance' to each staircase - at every floor, of suitable size, in proper relationship to elevators/lifts
- all robustly fire protected - fire resistance (heat / smoke / flame) plus resistance to mechanical damage > hardcore is a must !

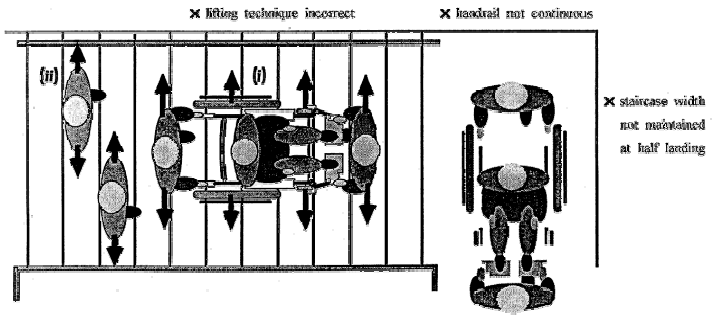
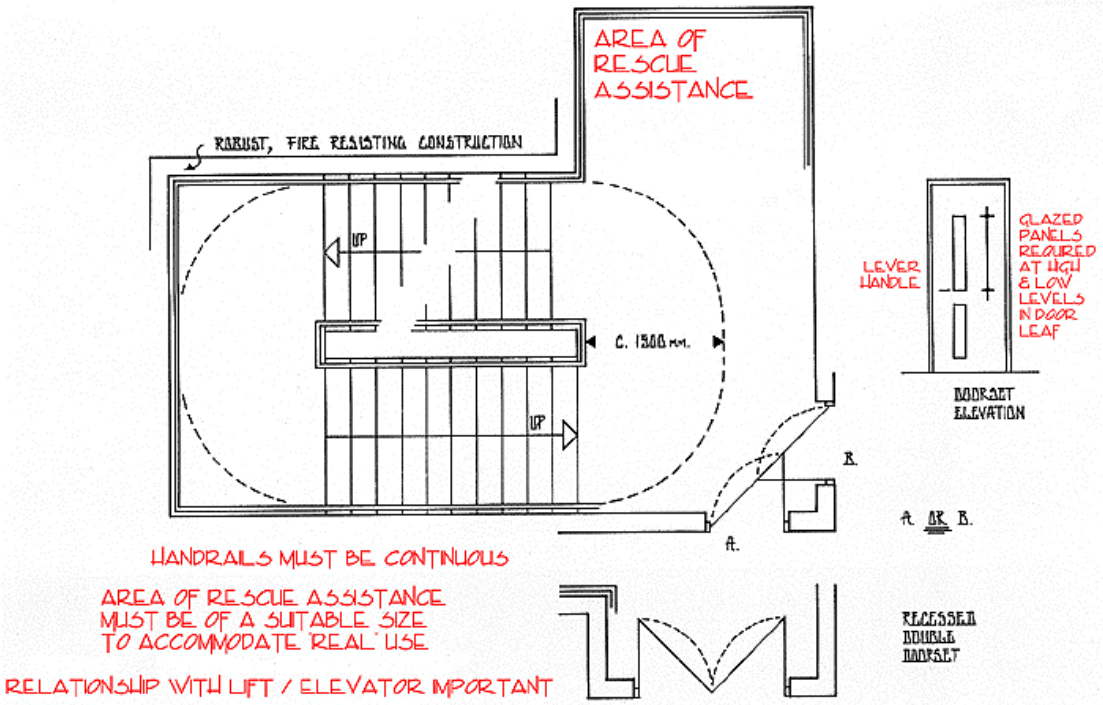


Fig. 3 Assisted Evacuation Down, or Up, a Stairway [15]
(i) wheelchair user
(ii) visually impaired



Staircase Design for Evacuation & Contraflow

http://www.fireox-international.com/fire/appendixd.htm

Area of Rescue Assistance ✔

(also known as a 'refuge' / 'refuge area' ✘)

A building space directly adjoining, and visible from, a main vertical evacuation route - robustly and reliably protected from heat, smoke and flame during and after a fire - where people may temporarily wait with confidence for further information, instructions, and/or rescue assistance, without obstructing or interfering with the evacuation travel of other building users.

An 'Area of Rescue Assistance' is a **'Place of Relative Safety'** ;
it is not a 'Place of Safety' !

Building Users / Fire Incident / No Explosion Hazard

Place of Safety :

Any location beyond a perimeter which is [100] metres from the fire building or a distance of [10] times the height of such building, whichever is the greater ..... **and**

where necessary medical care and attention can be provided, or organized, within one hour of injury ..... **and**

where people can be identified.

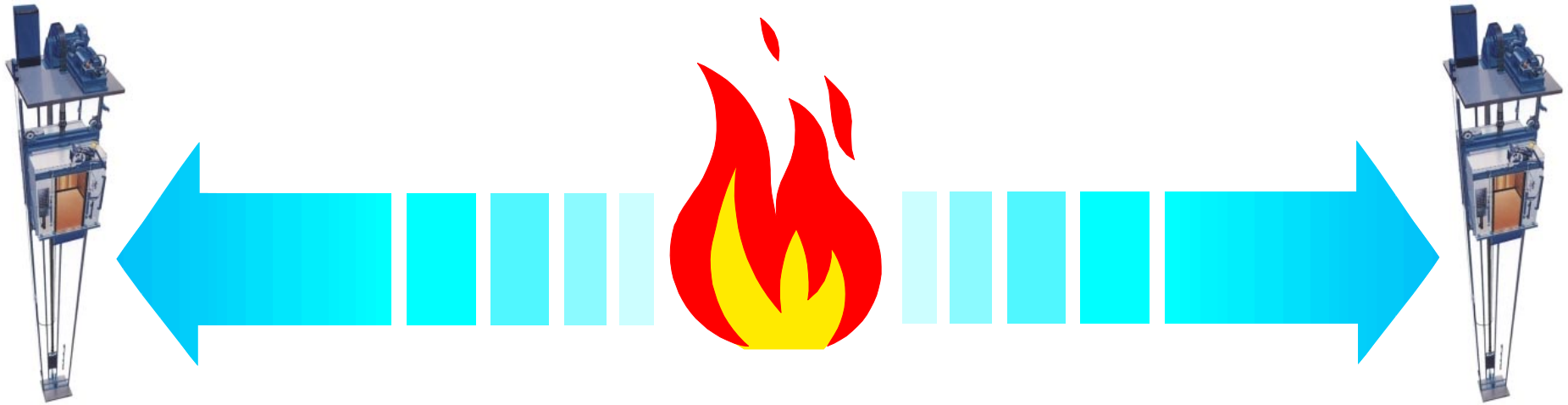
'Protecting Health' v 'Assessing Risk to Safety'

Health : A state of complete physical, mental and social wellbeing, and not merely the absence of disease and infirmity. (WHO)

Building Design for Firefighter Safety ?!?

http://www.FirefighterCloseCalls.com
http://www.EveryoneGoesHome.com

Clear & Alternative



Means of Evacuation

(for people with activity limitations)

[Alternative & Protected Means of Attack for Firefighters]

Structural Fire Engineering

Those aspects of fire engineering concerned with
structural design for fire,

and the complex interaction between
a building's structure and fabric, i.e. non-structure,

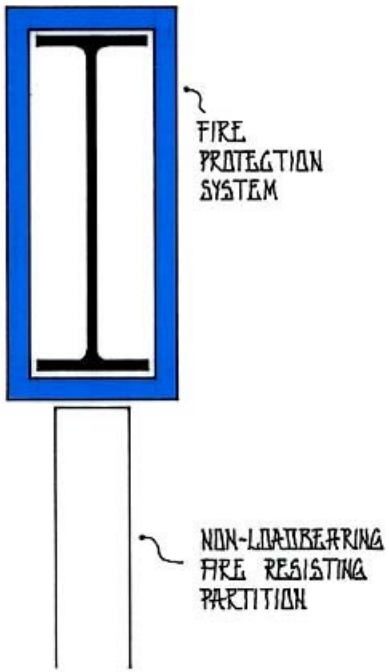
under conditions of fire
and its aftermath.

..... applies to all buildings !

A Typical Architectural Detail .....

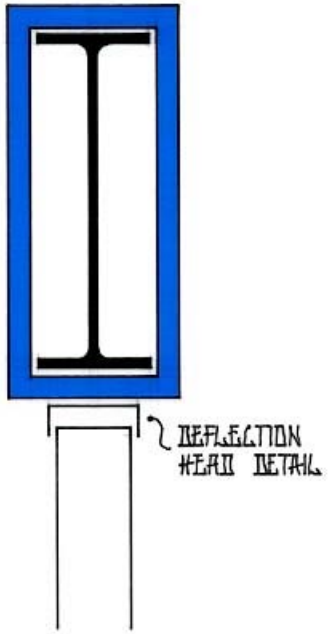
Situation A

..... no deflection possible



Situation B

..... limited deflection possible



Fire Resistance

The inherent capability of a building assembly, or an element of construction, to resist the passage of heat, smoke and flame for a specified time during a fire.

Structural Reliability

(ISO 2394 : 1986 + Addendum 1 : 1988)

The ability of a structural system to fulfil its design purpose, for a specified time, under the actual environmental conditions encountered in a building.

In structural design for fire, the concern must be that the structure will fulfil its purpose, both during the fire - and for a minimum period afterwards, during the 'cooling phase'.

[Limit State Design .... Ultimate Limit State & Fire Serviceability Limit States]

Fire Compartmentation

The division of a building into fire-tight compartments, by fire resisting elements of construction, in order .....

- to contain an outbreak of fire ;
- to prevent damage, within the building, to other adjoining compartments and/or spaces ;
- to protect a compartment interior from external fire attack, e.g. fire spread across the building's facade or from an adjacent building ;
- to minimize adverse, or harmful, environmental impacts outside the building.

Progressive Collapse

The sequential growth and intensification of distortion, displacement and failure of elements of construction in a building - during a fire and the 'cooling phase' afterwards - which, if unchecked, will result in disproportionate damage, and may lead to total building collapse.

Progressive collapse can commence before a breach in the 'integrity' of a fire compartment.

Disproportionate Damage

The failure of a building's structural system .....
(i) remote from the scene of an isolated overloading action ; and
(ii) to an extent which is not in reasonable proportion to that action.

European Union Council Directive 89/106/EEC

on the approximation of laws, regulations and administrative provisions of the Member States relating to **Construction Products** ~ 21st December 1988

Essential Requirements

1. Mechanical Resistance & Stability

The construction works must be designed and built in such a way that the loadings that are liable to act on it during its construction and use will not lead to any of the following :

(a) collapse of the whole or part of the works ;
(b) major deformations to an inadmissible degree ;
(c) damage to other parts of the works or to fittings or installed equipment as a result of major deformation of the load-bearing construction ;
(d) damage by an event to an extent disproportionate to the original cause.

2. Safety in Case of Fire

The construction works must be designed and built in such a way that in the event of an outbreak of fire :

- the load-bearing capacity of the construction can be assumed for a specific period of time ;
- the generation and spread of fire and smoke within the works are limited ;
- the spread of the fire to neighbouring construction works is limited ;
- occupants can leave the works or be rescued by other means ;
- the safety of rescue teams is taken into consideration.

Unprotected steel is prone to Progressive Collapse.

All structural steelwork must, therefore, be properly protected from fire.

In 'real' buildings, this also means that fire protection must be able to withstand mechanical damage - before, and during a fire with its 'cooling phase'.

A fundamental re-examination of lightweight fire protection methods is now very necessary.

NIST WTC 1 & 2 Final Report - Recommendation 10

NIST recommends the development and evaluation of new fire resisting (steel protection) coating materials, systems, and technologies with significantly enhanced performance and durability to provide (fire) protection following major events.

[Footnote 34 suggests that Sprayed Fire Resisting Materials could be encapsulated by highly elastic energy absorbing membranes, or commodity grade carbon fibre, or other wraps.]

Serviceability limit state design of structures for fire must become the norm.

Following the WTC Incident (9-11), the concepts of 'resistance to progressive collapse' and 'resistance to disproportionate damage' must be comprehensively introduced to all aspects of fire engineering education and practice.

NIST WTC 1 & 2 Final Report - Recommendation 1

NIST recommends that: (a) progressive collapse be prevented in buildings; and (b) a standard methodology be developed to reliably predict the potential for complex failures in structural systems subjected to multiple hazards (at the same time).

NIST WTC 1 & 2 Final Report - Recommendation 1a

Progressive collapse is addressed only in a very limited way in (current) practice, and by (current) codes and standards. NIST recommends that initiating events at multiple locations within the structure should be analyzed commensurate with the risks considered in the design.

NIST WTC 1 & 2 Final Report - Recommendation 1b

A robust, integrated predictive capability should be developed, validated and maintained to routinely assess the vulnerability of whole structures to the effects of credible hazards. This capability to evaluate the performance and reserve capacity of structures does not exist, and is a significant cause for concern.

NIST WTC 1 & 2 Final Report - Recommendations 4 & 9

NIST recommends the development of standards and code provisions to enable the design and retrofit of structures to resist 'real' building fire conditions, including their ability to achieve the (fire engineering design) objective of burnout in a 'maximum credible fire scenario', without structural or local floor collapse .... recognizing that sprinklers could be compromised, not operational, or non-existent.

[Footnote 26 states that a 'maximum credible fire scenario' includes conditions which are severe, but reasonable to anticipate .... related to building construction, occupancy, fire loads, ignition sources, compartment geometry, fire control methods .... and adverse, but reasonable to anticipate, operating conditions.]

Non-robust, 'soft core' construction is only adequate in small, very simple buildings types.

NIST WTC 1 & 2 Final Report - Recommendation 18

As the last line of defence for life safety, the stairwells and elevator shafts individually, or the core if these egress components are contained within the core, should have adequate structural integrity to withstand accidental structural loads and anticipated risks.

If bolting is used to connect steel members in steel-frame construction, sufficient welded connections must be located at strategic parts of the frame.

With regard to protection from fire of the people using a building (occupants, visitors and other users), a building's capacity to accommodate a 'maximum credible user scenario' during a fire incident, i.e. user conditions which are severe but reasonable to anticipate, must be clearly shown.

All evacuation routes in buildings must be designed to Accessibility Design Standards.

http://www.fireox-international.com/fire/appendixd.htm

NIST WTC 1 & 2 Final Report - Recommendation 17

NIST recommends that stairwell capacity and stair discharge door width should be adequate to accommodate contraflow due to emergency access by firefighters/rescue teams.

[Footnote 39. NIST found that the average surviving occupant in the WTC Towers descended stairwells at about half the slowest speed previously measured for non-emergency evacuations.]

Following the WTC Incident (9-11), fire engineering and conventional ('ambient') structural engineering must be seamlessly integrated.

NIST WTC 1 & 2 Final Report - Recommendation 28

NIST recommends that the role of 'Design Professional in Responsible Charge' be clarified.

[Footnote 49 states that the 'Design Professional in Responsible Charge' ensures that All Members of the Building Design Team use consistent design data and assumptions, co-ordinates overlapping specifications, and serves as the liaison between all parties involved in the project, including enforcement and review officials, and the client or client organization.]

Technical Control

NIST urges state and local agencies **to rigorously enforce** building codes and standards since such enforcement is critical to ensure the expected level of safety.
Unless they are complied with, the best codes and standards cannot protect occupants, emergency responders, or buildings.

[Last Paragraph, Executive Summary, NIST WTC 1 & 2 Final Report]

Still one more conceptual leap is required - to ensure that 'real' structural performance is 'reliability-based' .... all related engineering disciplines must gear up to understand and practice Sustainable Engineering, i.e. Ethical Engineering Design.

http://www.fireox-international.com/sustain/sustainableengineering.htm

Firefighters / Emergency Responders

NIST recommends the establishment and implementation of codes and protocols for ensuring effective and uninterrupted operation of the **command and control system** for large-scale emergencies.

[NIST WTC 1 & 2 Final Report - Recommendation 24]

Command posts should be established outside the potential collapse footprint of any building which shows evidence of large multi-floor fires or has serious structural damage.

[NIST WTC 1 & 2 Final Report - Recommendation 24c]

Actions should be taken via training and drills to ensure a co-ordinated and effective emergency response at all levels of the incident command chain by requiring all emergency responders that are given an assignment to **immediately adopt and execute** the assignment objectives.

[NIST WTC 1 & 2 Final Report - Recommendation 24e]

National, Regional & Local Governmental Authorities

NIST recommends that such entities be encouraged to provide **a level of safety that equals or exceeds** the level of safety that would be provided by **strict compliance** with the code requirements of an appropriate governmental jurisdiction.

To gain broad public confidence ..... NIST further recommends that **as-designed and as-built safety** be certified by a qualified third party, independent of the building owner(s). The process should **not use self-approval** for code enforcement in areas including interpretation of code provisions, design approval, product acceptance, certification of the final construction, and post-occupancy inspections over the life of the buildings.

[NIST WTC 1 & 2 Final Report - Recommendation 25]

Building Operation Instruction Manual

NIST recommends that building codes (and standards) incorporate a provision that requires building owners to (reliably) **retain documents**, including supporting calculations and test data, related to building design, construction, maintenance and modifications **over the entire life of the building**. Means should be developed for (duplicate) off-site storage and maintenance of the documents.

In addition, NIST recommends that relevant **building information be made available** in suitably designed hard copy or electronic format for use by (firefighters / rescue teams and other) **emergency responders**. Such information should be easily accessible by responders during emergencies.

[NIST WTC 1 & 2 Final Report - Recommendation 27]

Disability & People with Activity Limitations

[2001 WHO ICF]

To the degree possible, **mobility-impaired occupants (??)** should be provided a means for self-evacuation in the event of a building emergency.

[NIST WTC 1 & 2 Final Report - Recommendation 17b]

NIST recommends that the full range of current and **next generation evacuation technologies** should be evaluated for future use, including fire protected and structurally hardened elevators/lifts, exterior evacuation devices, and stairwell descent devices, which may allow **all occupants an equal opportunity (??)** for evacuation and facilitate emergency response access.

[NIST WTC 1 & 2 Final Report - Recommendation 20]

Fire Engineering Design Objectives

Ethical Fire Engineering Design Practice, i.e. to properly protect society's interests, and the interests of the client / client organization .....

1. Protection of the health of all building users, including people with activity limitations, visitors to the building who may be unfamiliar with its layout, and including contractors or product / service suppliers temporarily engaged in work or other business transactions ;
2. Protection of property, including the building, its contents, and adjoining or adjacent properties, from fire loss or damage ;
3. Protection of the safety of firefighters / rescue teams ;
4. Buildability of necessary re-construction after a fire ;
5. Protection of the 'natural environment' from adverse or harmful impacts ;
6. Sustainability of the 'built environment' - including the proper selection, and life cycle assessment (see EN ISO 14040) / costing, of fire engineering related materials, products, components, systems, etc., fixed, installed or incorporated in the building.