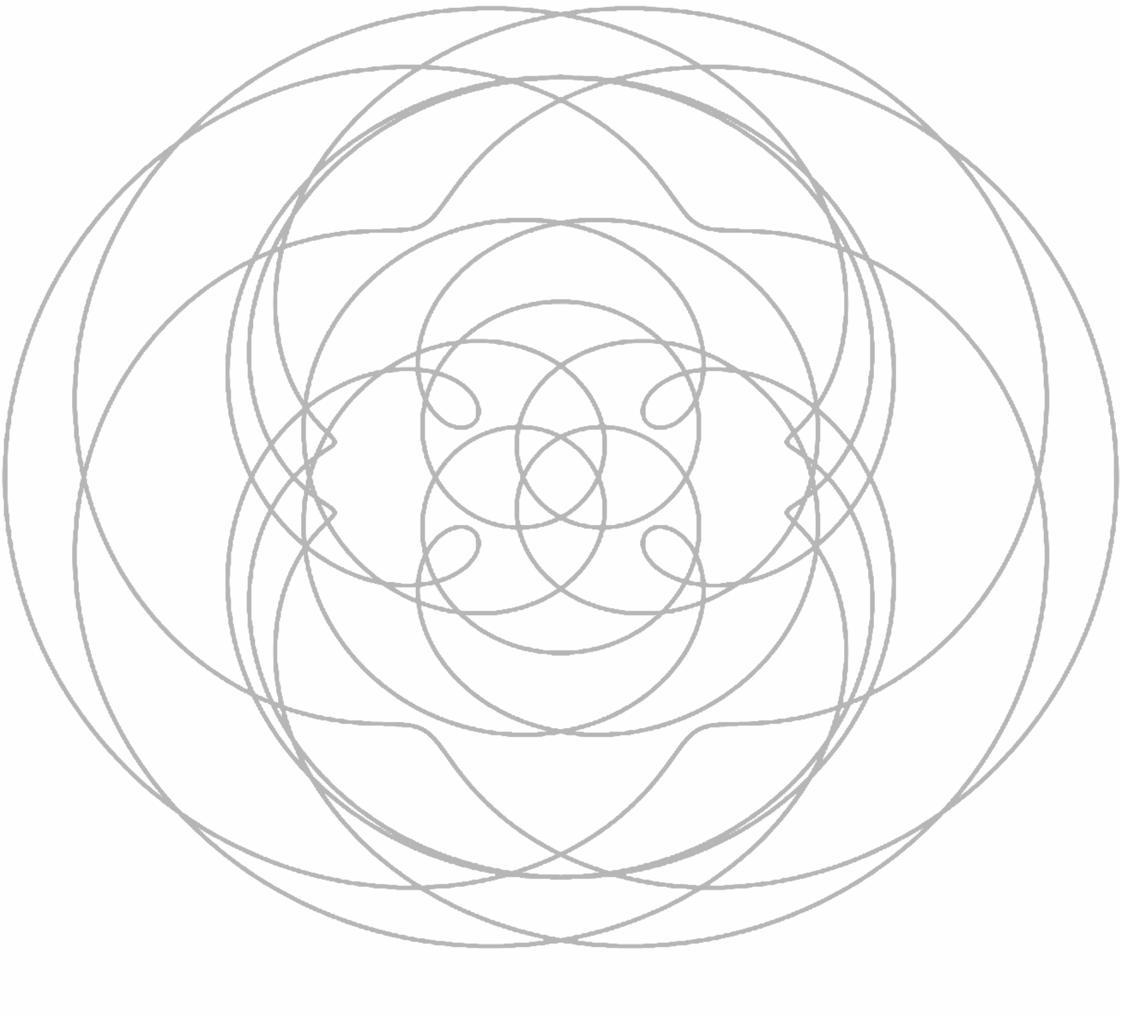
EPICYCLES

of

INEVITABILITY



The Refusal to Pretend to Know

Monitum: De Diversis Opinionibus

A quarter-century has passed, yet if you ask how the Twin Towers fell, you will be met not with a single answer, but with a veritable choir. Even among the credentialed, the explanations form a dissonant cacophony of contradictory “obviousness”:

- *“It was a hammer-blow of mass.”* vs. *“It was a zipper-like sequence of connections.”*
- *“The core was hollowed out.”* vs. *“The core was redundant and robust.”*
- *“It was basic Newtonian F=ma.”* vs. *“It was emergent behavior beyond simple reduction.”*
- *“The steel melted.”* vs. *“The steel sagged.”* vs. *“The steel fractured.”*

We are told there is a “robust expert consensus,” yet the diversity of these claims suggests otherwise. When explanations are mutually exclusive, they cannot all be true. When “inevitability” is invoked to bypass mechanical proof, science has been replaced by rhetoric.

If our best argument for a world-changing event is simply that *“all the smart people agree,”* we have no right to mock the flat-earther. A consensus that cannot be clearly articulated or validated is not science; it is a decree.

Epicycles of Inevitability does not seek to invent a new mystery. It seeks to determine exactly *what* the official explanation is—and whether it stands on the firm ground of validation, or the circular logic of retrospective obviousness. It is time to stop pretending we know what we have not yet proven.

What This Document Argues — and What It Does *Not* Argue

This document argues	This document does not argue
That claims of *inevitability* require demonstration of robustness under variance	That “controlled demolition” or any specific alternative mechanism occurred
That progression modeling across ensembles is necessary to support inevitability claims	That absence of such modeling proves any competing hypothesis
That existing explanations rely heavily on calibrated, non-ensemble, partially opaque models	That investigators acted with intent, malice, or conspiracy
That observed outcomes exhibit features suggestive of **narrow basins** in model space	That narrow basins imply design, intent, or external intervention
That the loss of evidence and simulation transparency increases epistemic uncertainty	That uncertainty constitutes proof of wrongdoing
That symmetric, rapid, non-arresting progression is technically non-trivial	That such progression is impossible under gravity and damage alone
That tall structures typically possess significant vertical reserve capacity	That reserve capacity is always sufficient to prevent progressive collapse
That a **positive research program** can decisively reduce uncertainty	That the matter is already resolved in favor of any alternative
That skepticism toward inevitability claims is methodologically justified	That official agencies or researchers are dishonest or incompetent
That basins, ensembles, and sensitivity should be made explicit	That any specific values or outcomes are predetermined

Short summary

> The document questions whether inevitability has been *shown*. It does **not** claim that inevitability is false, nor does it propose a substitute theory.

Epistemic Limits and Claims of Inevitability

(The Refusal to Pretend to Know: Pt. I)

Abstract

Post-event analyses of the World Trade Center (WTC) collapses frequently characterize the global collapse of the towers as *inevitable* once initiation occurred, while also acknowledging that the collapses were a profound surprise to experienced structural engineers. Part I of *Epicycles of Inevitability* examines the logical and epistemic tension between surprise and inevitability, and between claims of design specificity and claims of generic collapse behavior. Without proposing alternative mechanisms, the paper evaluates whether the confidence commonly expressed about inevitability is commensurate with the scope, validation, and predictive power of the analyses performed. It argues that retrospective certainty has outpaced demonstrated understanding, and that greater epistemic humility and curiosity are warranted in the interpretation of rare, catastrophic structural failures.

1. Introduction

The collapses of the WTC towers represent among the most consequential structural failures in modern history. Considerable analytical effort has been devoted to reconstructing the initiating mechanisms and explaining the subsequent global collapse. These efforts have yielded plausible and internally consistent narratives grounded in accepted principles of structural mechanics, fire effects, and gravity-driven progression.

However, beyond plausibility, many accounts go further, asserting that collapse was *inevitable* once initiation occurred, and that detailed modeling of collapse progression was therefore unnecessary. At the same time, the collapses are widely described—by investigators and researchers alike—as unprecedented and surprising.

Part I of *Epicycles of Inevitability* examines whether these positions can be held simultaneously without contradiction, and whether the level of confidence often expressed is justified by the degree of validation achieved. The focus is not on disputing conclusions, but on evaluating the epistemic standards by which those conclusions are framed.

2. Surprise as Epistemic Evidence

In engineering failure analysis, *surprise* is not merely a psychological reaction; it is an epistemic signal. When experienced practitioners are collectively surprised by an outcome in their own domain, this typically indicates either:

1. Operation in a regime outside normal design and analytical assumptions, or
2. Incompleteness in prevailing models or conceptual frameworks.

In the case of the WTC collapses, surprise was widespread. Statements by structural engineers, emergency managers, and investigators indicate that global progressive collapse was not anticipated in real time, even after aircraft impact and prolonged fire exposure. [BAZANT-405]

If collapse progression was truly obvious and inevitable under the observed conditions, then this collective surprise demands explanation. The least informative explanation—that experts simply failed to recognize the obvious—offers little insight into structural behavior and undermines confidence in professional judgment. More plausibly, the surprise suggests that the governing failure mechanisms were not transparent within the analytical frameworks available at the time.

Treating surprise as irrelevant after the fact risks discarding valuable information about the limits of understanding that existed prior to observation.

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3. Retrospective Inevitability and Predictive Power

Claims of inevitability in engineering carry specific implications. An outcome described as inevitable is generally understood to follow deterministically from initial conditions across realistic variations in parameters, geometry, and material properties. Such claims are strongest when supported by models that demonstrate robustness, sensitivity bounds, and predictive capability.

In the WTC case, post-event analyses demonstrate that gravity-driven collapse is *compatible* with energy considerations and plausible failure sequences. However, compatibility is not equivalent to inevitability. Models constructed after the fact are calibrated to known outcomes; they do not, by themselves, establish that alternative outcomes—such as partial collapse or arrest—were impossible under slightly different conditions.

The absence of detailed progression modeling and systematic arrest analysis limits the strength of inevitability claims. In nonlinear, threshold-sensitive systems, small variations can produce qualitatively different outcomes. Without ensemble analysis across such variations, inevitability remains an assertion rather than a demonstrated property.

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4. Design Specificity and Generality

Explanations of the WTC collapses frequently invoke the towers' "unique" design features to account for the rarity of the event, while simultaneously asserting that progressive collapse, once initiated, would occur in essentially any tall building due to basic physics.

These two positions imply different regions of applicability. If design specifics are critical, then the collapse occupies a narrow region of design and damage space, and generalization to other structures is limited. If, instead, collapse progression is largely design-independent, then similar failures should be expected more frequently, which empirical experience does not support.

Initiation and progression cannot be cleanly separated in this way. Structural configuration, load paths, redundancy, and reserve capacity influence both. Appeals to uniqueness when explaining rarity, and to generality when asserting inevitability, reflect a rhetorical convenience rather than a resolved understanding of where collapse behavior lies within the broader design space.

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5. Modeling Scope and Epistemic Closure

A central methodological decision in the official investigation was to terminate detailed analysis at the point of global collapse initiation. The justification offered was that progression was inevitable and therefore did not require further study [NCSTAR-1, BAZANT-466].

From an epistemic standpoint, this reasoning is circular. Inevitability of progression is precisely the claim that would require demonstration through progression modeling, resistance quantification, and arrest analysis. Declaring inevitability in order to justify not modeling progression reverses the normal logic of engineering inquiry.

This is not a critique of practicality or resource constraints, but of inference. When modeling stops short of the phenomenon under discussion, confidence in claims about that phenomenon should be correspondingly constrained.

5.5 The Evidential Basis for Claims of Inevitability

NIST terminated detailed analysis at collapse initiation, stating in footnotes that progression modeling was unnecessary because “collapse became inevitable.”[NCSTAR-1, pp. xxxvii, 82]

NIST did not model:

- Story-by-story resistance through the lower structure
- Arrest conditions or probabilities
- Sensitivity to structural or thermal variance
- Partial collapse outcomes

Analytical treatment of progression appears in NCSTAR 1-6, p. 323, where NIST reviews Bažant & Zhou (2002) and states: “NIST agrees with the assessment.”

Bažant & Zhou (2002):

The paper states its aim explicitly:[BAZANT-405]

> “We are not attempting to model the details of the real failure mechanism but seek only to prove that the towers must have collapsed and do so in the way seen.”

Method:

- Energy-balance model of repeated impacts causing multi-floor buckling
- Assumes rigid upper block (“important hypothesis” to maximize resistance)
- Uses “optimistic assumptions” for stiffness and force distribution
- Calculates $W_g/W_p \approx 8.4$ initially, dropping to ~1% dissipation during descent
- Concludes arrest impossible, collapse “almost free fall”

What this demonstrates:

- Under stated assumptions, energy favors progression
- Energy imbalance worsens as mass accumulates

What this does not demonstrate:

- Robustness across parameter variance
- Sensitivity to assumptions (rigid block, stiffness, dissipation modes)
- Arrest probability under heterogeneous conditions
- Effect of geometric or material scatter

Later work:

Bažant & Verdure (2007) characterize progression modeling as “superfluous” for proving inevitability, stating it is useful for “learning from demolitions” and “dispelling myths.”[BAZANT-466] The model is calibrated to observed collapse time and characteristics (Chapter 6).

Evidential status:

- NIST: Progression not modeled because inevitable
- Bažant/Zhou: Inevitability from energy balance under single parameter set
- Neither: Ensemble analysis, variance testing, or arrest statistics

Inevitability claims rest on:

- One energy-balance model
- Assumptions stated to maximize resistance
- No demonstration of robustness across uncertainty
- Calibration to observation (not independent validation)

An outcome can be energetically favored under specific assumptions without being inevitable across realistic variability. The latter requires ensemble demonstration, which has not been provided.

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6. Retrospective Obviousness and Historical Precedent

Historical precedents in structural engineering illustrate a different response to surprise. The collapse of the Tacoma Narrows Bridge, for example, revealed a poorly understood aeroelastic instability. Surprise prompted extensive experimental, theoretical, and code-level developments, and the event is now recognized as exposing a genuine gap in prior understanding.

In contrast, the WTC collapses are often described as retrospectively obvious, despite comparable expressions of surprise at the time. This asymmetry is noteworthy. In one case, surprise motivated deeper inquiry and framework revision; in the other, surprise is treated as a transient misperception, corrected by post-hoc reasoning.

Such retrospective obviousness risks conflating explanation with understanding. **An explanation that fits known facts does not automatically imply that the phenomenon was predictable or that the governing principles are fully understood.**

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7. Intellectual Honesty and Standards of Confidence

Scientific and engineering integrity depend not only on producing plausible explanations, but on calibrating confidence to evidence. Overstated certainty can be as misleading as unwarranted doubt.

A more epistemically cautious position would distinguish between:

- **What is demonstrated:** plausibility, internal consistency, and compatibility with known physics
- **What remains uncertain:** robustness across variance, arrest probabilities, and generalizability to other structures

Acknowledging uncertainty does not weaken the explanatory framework; rather, it strengthens it by aligning claims with demonstrated scope.[FEYNMAN-1974]

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8. Implications for Engineering Practice

The way the WTC collapses are framed has implications beyond historical understanding. Claims of inevitability influence:

- risk assessment and emergency decision-making
- design philosophy regarding robustness and disproportionate collapse
- research priorities in fire-structure interaction and progressive collapse

If collapse progression is truly generic and inevitable, then prevention must focus almost entirely on avoiding initiation. If, instead, progression depends sensitively on design and conditions, then understanding arrest mechanisms becomes equally important.

At present, the strength of inevitability claims exceeds the evidentiary basis required to resolve this distinction.

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9. Conclusion

The WTC collapses revealed structural behavior that surprised experienced engineers. That surprise is evidence of epistemic limits at the time of the event. Post-event analyses have produced plausible explanations consistent with accepted mechanics, but plausibility should not be conflated with inevitability.

Intellectual honesty in engineering requires that confidence be proportional to validation, and that surprise be treated as a prompt for deeper inquiry rather than something to be explained away. A posture of epistemic humility—recognizing what is understood, what is inferred, and what remains uncertain—better serves both science and public trust than retrospective claims of obviousness.

The enduring lesson of the WTC collapses may not be that the outcome was inevitable, but that rare failures can expose the boundaries of our understanding. Respecting those boundaries is a prerequisite for extending them.

Summary Table: Epistemic Tensions

Paradox	Position A	Position B	What It Reveals
Modeling Scope	"Most detailed investigation ever"	"Progression not worth modeling"	Delimited Scope applied to support working hypothesis
Residue Testing	"No evidence of explosives"	"We didn't test for explosives"	Absence of testing treated as negative result
Steel Preservation	"Largest mass murder"	"<1% of steel saved"	Investigation scope didn't match event magnitude
Temperature Evidence	"Fires weakened steel"	"No steel >600°C found"	Physical evidence doesn't support thermal narrative
Jet Fuel	"Jet fuel critical"	"Jet fuel burned in minutes"	Early explanations fundamentally wrong
Burnout Timing	"Fires caused collapse"	"Fires nearly done"	Timing suggests mechanism more complex than claimed
Oscillation Period	"Critically damaged"	"Nearly undamaged frequency"	Sudden transition from robust to failed unexplained
Column Loading	"Columns overloaded"	"Huge lateral design reserves"	Required loading levels not demonstrated
Fire Sensitivity	"Collapse depends on fires"	"Fire models insensitive"	Gap between fire robustness and structural sensitivity
Core Description	"47 box columns"	"Hollow shaft"	Fundamental structural misunderstanding
Symmetry	"Asymmetric damage"	"Symmetric collapse"	Centering mechanism not identified
Modeling Selectivity	"Model everything needed"	"Skip controversial parts"	Selective application of rigor

> In general, we look for a new law by the following process: First we guess it; then we compute the consequences of the guess to see what would be implied if this law that we guessed is right; then we compare the result of the computation to nature, with experiment or experience, compare it directly with observation, to see if it works. If it disagrees with experiment, it is wrong. In that simple statement is the key to science. It

does not make any difference how beautiful your guess is, it does not make any difference how smart you are, who made the guess, or what his name is — if it disagrees with experiment, it is wrong.
— *Richard Feynman*

Dialectic Inventory

(The Refusal to Pretend to Know: Pt. II)

Preamble

This document examines the mechanical and methodological foundations of the prevailing explanation for the progressive collapse of tall steel-framed structures under combined damage and fire. Its purpose is precise and limited: to evaluate whether claims of inevitability, robustness, and sufficiency meet the standards of evidence, transparency, and reproducibility that scientific disciplines demand.

We evaluate one claim only: **that the observed outcomes followed from known mechanisms in a manner that is physically, methodologically, and epistemically well-established.** We do not argue for alternatives, prove competing hypotheses, or rely on insinuation, anomaly-hunting, or motivated reasoning. We do not dispute possibility, argue impossibility, imply intent, or promote unmentioned theories. The aim is to insist that any explanation claiming scientific status submit to scientific standards.

History provides precedent: Geocentric epicycles, miasma theory, and phlogiston endured through premature closure, rhetorical insulation, and plausibility over demonstration. Avoidance requires method, not consensus or credential.

Our standard is simple:

> **Claims about inevitability must show inevitability.**
> **Claims about robustness must show robustness.**
> **Claims about prediction must predict.**

Anything else is persuasion, not science.

Critiquing the record on its merits risks bias charges; proposing alternatives invites speculation dismissal. This document does neither—assessing only whether the claimed explanation meets its standards of inevitability, without addressing gaps. We will restate scope once again at the very end. Nowhere else.

Scope of Analysis

This document addresses the mechanics of downward progressive collapse through largely intact structural steel once vertical motion is underway.

It does **not** address fire initiation scenarios, detailed temperature reconstructions, or debates over ignition sources. Those questions are orthogonal.

The central question is strictly mechanical: **Given the observed progression, were the structural resistances and energy transfers quantitatively sufficient to produce the descent characteristics through predominantly cold steel?**

That is where the diagnostic difficulty lies, and where the analysis is focused.

Chapter 1 — Framing the Problem

1.1 The Claim Under Examination

The core claim: Given aircraft impact damage and fires, progressive gravitational collapse was **inevitable**, or nearly so, once downward movement initiated. Accompanying assertions: The mechanism is **well understood** and **fully explained** within conventional structural mechanics.

This document evaluates whether those assertions meet ordinary standards for complex failure analysis, focusing on:

- Mathematical structure of models
- Transparency of inputs and parameters
- Calibration vs. validation distinction
- Variance and uncertainty treatment
- Ensemble analysis presence
- Asserted inevitability vs. demonstrated robustness
- Consistency of energy, momentum, and resistance

The evaluation concerns **method**, not belief.

1.2 What Would Constitute Adequate Support

Adequate support for inevitability or robustness requires:

- full publication of governing equations and boundary conditions
- public availability of model inputs or executable simulation code
- sensitivity analyses showing parameter dependence
- ensemble modeling across realistic material and geometric variance
- explicit reporting of arrest frequencies, partial failures, and runaways
- clear separation between assumptions, calibration, and inference
- quantification of uncertainty, not rhetorical confidence

These are not extraordinary demands or ‘impossible’ standards. They mirror normal practice in fracture mechanics and reliability engineering, and structural risk assessment.

1.3 What We Actually Observe in the Literature

Prominent analytical treatments exhibit recurring features [BAZANT-405, BAZANT-466, BAZANT-476, BAZANT-499, BAZANT-585, BAZANT-625, BAZANT-EPN]:

- **upper blocks treated as rigid bodies**
- **force–displacement functions assumed or idealized rather than measured**
- **known unknowns replaced by constant surrogates**
- **energy dissipation localized to advancing crush fronts**
- **calibration to observed duration and mass ejection to determine parameters**
- **progression treated as one-dimensional and centrally aligned**
- **sensitivity studies largely absent or fragmentary**
- **key resistive terms introduced or omitted between papers without systematic reconciliation**

These do not render the models invalid. They define their epistemic status:

> **plausibility constructions conditioned on assumptions**, not yet fully validated dynamical accounts.

When such models are used to claim **inevitability**, that is where the methodological tension arises.

1.4 The Central Question

The central technical question is this:

> Does progressive floor-by-floor collapse occur across a broad region of realistic parameter space, or only within narrow, tuned conditions?

This distinguishes:

- **robust outcome** vs. **sensitive trajectory**
- **“could”** vs. **“must”**
- **explanation** vs. **curve-match**

The answer depends on:

- energy balance
- momentum transfer
- post-yield connection behavior
- heterogeneity
- stochastic variance
- dynamic scaling with height and mass
- ensemble statistics

At present, assertions of robustness exceed what has been empirically demonstrated.

1.5 What This Document Is Not

This document does *not*:

- argue that collapse was impossible
- infer intent
- promote "alternative theories"
- rely on insinuation, anomaly-hunting, or motivated reasoning

It does only this:

> evaluates whether the prevailing explanation satisfies the evidential and methodological designed to prevent new epicycles.

1.6 The Null Hypothesis and Burden of Proof

In scientific reasoning, the null position is not "collapse happened, therefore the explanation is valid," but rather:

> Progressive collapse is not inevitable under realistic variance—robustness must be demonstrated, not presumed.

This null hypothesis does not deny possibility. It restricts claims of necessity to standards commensurate with their strength.

Chapter 2 — The Replication Difficulty

2.1 Why Replication Matters

Replication is diagnostic because robust outcomes recur under variation. A mechanism claimed to be generic and dynamically inevitable should not require delicate tuning to reproduce or depend on narrow corridors of coincidence.

Replication here means:

- explicit assumptions
- published equations
- publicly testable implementations
- ensemble runs rather than hand-selected cases
- reporting of failure and arrest rates

We evaluate the situation against that standard.

2.2 What Should Be Demonstrable

If progressive gravitational collapse under damage and fire is a **broad, stable attractor**, models should reveal:

- reproducible downward progression without requiring fine adjustment
- arrest events occurring at quantifiable rates under realistic variance
- partial collapses appearing as common outcomes
- asymmetries developing naturally in heterogeneous structures
- collapse duration varying in structured ways tied to inputs

In other words: a **population of behaviors**, not a **single narrative trajectory**.

This does not require perfect realism. It requires honesty about what the mechanism does under perturbation.

2.3 What We Actually See

Instead, the record shows:

- calibration to the historical event
- selection of parameters to fit observations
- idealized post-yield behavior
- homogenization of heterogeneity
- systematic reduction of lateral DOFs
- sparse sensitivity analyses
- absence of large-scale ensemble studies
- visually persuasive but method-opaque animations

This does not falsify prevailing explanations. It shows that claims of inevitability remain unsubstantiated.

2.4 The Limits of Post Hoc Calibration

Fitting a single trajectory after parameter selection establishes compatibility, not necessity.

A model may match observation while being:

- sensitive to initial conditions
- dependent on tuned thresholds
- critically reliant on assumptions
- fragile under variance

Calibration is retrodiction. Validation requires **independent predictive survival**.

2.5 Heterogeneity and the Default Expectation

Tall steel structures are highly redundant, heavily overdesigned against gravity, and structurally heterogeneous SALVADORI-1979, SALVADORI-1982. Fire does not homogenize a structure; it increases irregularity. Damage does not align failure fronts; it amplifies asymmetry.

The default expectation in systems with:

- distributed load paths
- staggered weakening
- imperfect symmetry
- variable local capacity

is not synchronized, centrally aligned, total collapse with low outcome diversity. The default expectation is **mixed outcomes**: partial failures, deflections, irregular progressions, and arrest events unless a dominant, self-reinforcing dynamic overwhelms variance across wide conditions. WP-WINDSOR, WP-PLASCO, WP-ONE-MERIDIAN-PLAZA, WP-RONAN-POINT

If such a dominant attractor exists, it must be demonstrated — not assumed.

2.6 The Razor-Edge Problem

Many treatments implicitly assume what must be shown:

- that global collapse follows once downward motion begins
- that resistance rapidly falls below required stopping force
- that momentum accumulation overwhelms heterogeneity
- that failure propagates faster than compensatory redistribution

But when these claims are tested analytically, they often resolve to **threshold conditions**: collapse proceeds if resistance falls below a tuned function of mass, height, and velocity; if connections behave in specific ways; if post-yield behavior conforms to assumed idealizations; if internal redundancy does not meaningfully absorb impulse.

Threshold dynamics are acceptable when presented as conditional. Problems arise when they are presented as robust inevitability without ensemble justification.

2.7 Absence of Ensemble Is Not Neutral

If inevitability is claimed, robustness must be demonstrated. If demonstration is expensive, certainty is expensive.

Absence of ensemble modeling does not support closure. It indicates unresolved status.

2.8 What Replication Difficulty Means

Replication difficulty does not imply impossibility or intent. It means:

the mechanism has not yet been demonstrated to be generically robust.

Chapter 3 — Constraints, Fine-Tuning, and Sequential Failure

3.1 Sequential Collapse Is a Constrained Process

Progressive, floor-by-floor gravitational collapse is not merely "downward motion." It is a **coordinated sequence of mechanical events** that must satisfy multiple constraints simultaneously:

1. the descending mass must retain coherence long enough to transmit impulse
2. each successive floor must fail dynamically on first engagement
3. resistance must not increase faster than available momentum
4. lateral instability must not divert or arrest progression
5. redistribution mechanisms must not stabilize the structure
6. asymmetries must not convert descent into tipping or partial collapse

Each of these is individually non-trivial. Their **simultaneous satisfaction over many stories** is what elevates the problem.

The issue is not whether such a sequence is possible. It is whether it is **dynamically generic** or whether it requires a narrow alignment of parameters **— fine-tuning**.

3.2 The Mutual-Constraint Problem

Each floor in a tall building has two contradictory design requirements:

- it must carry gravity loads with safety margins under service conditions
- it must fail decisively under dynamic overload from above

These demands do not automatically coexist. Safety factors, redundancy, and ductility are introduced precisely to **prevent** dynamic failure cascades. Columns are not designed as fuses.

For sequential crushing to proceed without arrest:

- static capacity must be sufficiently high for normal service, while
- dynamic capacity must be sufficiently low that the descending mass exceeds it over and over again

This places the system near a threshold surface in parameter space. Move away from that surface — via material variability, connection behavior, residual strength, geometric imperfection — and the sequence breaks down.

3.3 What Structures Normally Do Instead

Real structures subjected to severe damage and uneven heating do not normally self-organize into clean, symmetric, floor-by-floor failure modes. They:

- redistribute loads
- develop plastic hinges
- shed nonstructural components
- stabilize in new geometries
- fail partially or asymmetrically
- arrest after partial progression

These behaviors are not exceptions; they are consequences of redundancy. Redundancy increases the number of available structural responses. It enlarges outcome space.

A mechanism that claims to produce:

- rapid progression
- symmetry
- non-arrest
- high completeness

must therefore identify the **specific dynamical process** that cancels exactly the redundancy designed to prevent it.

3.3.5 The Implicit Material: A Thought Experiment

Critics sometimes object that *Epicycles of Inevitability* “proposes no alternative explanation.” This misunderstands its purpose, which is methodological rather than mechanistic. However, the objection invites a useful thought experiment:

What material properties would be required for the observed behavior to follow generically from the stated mechanisms?

The answer is instructive. Consider a hypothetical substance—call it an **Anti-Newtonian Solid**:

- Under **static or slow loading**, it exhibits high strength and stiffness (supporting building service loads with large safety margins).
- Under **rapid dynamic loading**, even from relatively small impacting masses, it progressively transforms into a low-resistance medium, offering minimal opposition to continued motion.

This is the inverse of a **Newtonian fluid** (which resists fast shear but flows under sustained stress). The Anti-Newtonian Solid resists sustained stress but yields catastrophically to rapid impact.

Structural steel does not behave this way.

Real steel under dynamic loading typically exhibits:

- **strain-rate hardening** (increased yield strength at high deformation rates)
- **energy absorption through plastic deformation**
- **fracture resistance** that scales with cross-sectional area

For progressive collapse to proceed as described—rapidly, symmetrically, without arrest, across dozens of stories—the structure must behave *as if* it possessed Anti-Newtonian properties: robust under service conditions, but offering vanishing resistance once dynamic descent begins.

This is not impossible. It is simply **not a generic property of steel structures**. It requires specific conditions:

- synchronous weakening across load paths
- suppression of lateral degrees of freedom
- minimization of energy dissipation mechanisms
- elimination of redistributive capacity

In other words, it requires the **very fine-tuning** that claims of inevitability deny.

The thought experiment clarifies the burden: showing that ordinary structural steel, under realistic variance, behaves like an Anti-Newtonian Solid in the relevant regime is precisely what ensemble modeling would test.

Until such demonstration, the "alternative explanation" required is not a competing mechanism—it is simply **ordinary steel acting like ordinary steel**.

3.4 Vertical Reserve Capacity and the "Overbuilt" Reality

High-rise design is governed primarily by:

- lateral drift limits
- global stability under P–Δ effects
- wind and seismic excitation
- buckling of slender columns

Meeting these constraints forces designers to provide substantial **axial reserve capacity** as a side effect. Columns typically operate far below Euler buckling load; axial failure is seldom the governing limit state.

This reserve is not merely theoretical. Analyses of fire exposure, load redistribution, and thermal weakening often show that even under severe impact and multi-floor fires, significant structural integrity persists for extended durations—consistent with the towers' actual survival time [BAILEY]. Yet the transition from this demonstrated robustness to assertions of *inevitable progression* typically occurs without showing how redundancy, heterogeneity, and dissipation are dynamically neutralized across many floors [BAZANT-499]. The result is an explanatory discontinuity: robustness is documented up to initiation, but inevitability is declared afterward, without demonstrating a *generic pathway* from one to the other. A complete account must bridge this gap by showing that the collapse attractor is broad enough to dominate despite the very mechanisms that enabled prolonged stability.

This means:

- gravity alone is normally insufficient to push tall buildings into runaway axial failure

- substantial additional mechanisms must act to suppress redistribution pathways and redundancy

The observed outcome therefore implies that the structure was driven into a **critical regime** where ordinary reserves were simultaneously neutralized across many floors. If this regime is claimed to be "inevitable," its basin of attraction must be shown to be large. That has not yet been demonstrated.

3.5 The Stability–Instability Razor

Sequential collapse requires a moving balance between two competing tendencies:

- stabilization through redistribution and ductility
- destabilization through accumulating mass and velocity

If stabilization dominates, the collapse arrests or becomes partial. If destabilization dominates too strongly, breakup and loss of coherence occur, preventing clean sequencing.

The observed phenomenon requires the system to ride a **narrow ridge**:

- coherent enough to crush repeatedly
- unstable enough to progress without arrest
- symmetric enough to avoid tipping
- dissipative enough to comminute massive volumes of material
- fast enough to maintain acceleration close to gravitational

This is not impossible. It is simply **not generic** unless shown otherwise.

3.6 Fine-Tuning as a Diagnostic Marker

Fine-tuning is present when:

- parameters must be narrowly specified
- small changes in assumptions produce different qualitative outcomes
- the observed behavior sits near threshold conditions
- ensemble variance generates mostly non-matching cases
- coherence, symmetry, and progression all require coordination

Fine-tuning does not imply intent. It implies **fragile dynamics** residing near critical boundaries in outcome space.

Claims of inevitability are claims that fine-tuning is absent — that the behavior is robust. That claim requires evidence across variability, not single-trajectory calibration.

3.7 The Problem of Reference Cases

When mechanisms are generic, reference cases abound:

- progressive collapse in concrete-frame buildings
- partial collapses under fire damage
- asymmetric failures due to eccentric loading
- local buckling without full-height destruction

What is rare — and therefore requires explanation — is:

- full-height global collapse
- rapid near-axial descent
- sequential floor-by-floor failure without arrest
- high comminution across most of the structure
- recurrence of the joint outcome twice in the same complex

Rarity does not invalidate an explanation. It **increases the burden of mechanistic demonstration**.

3.8 Sequential Failure Is Not the Default Attractor

In dynamical systems language:

- sequential collapse is a candidate attractor
- redundancy, redistribution, and asymmetry compete attractors
- the system's actual trajectory depends on basin geometry

A claim of inevitability is a claim that the basin of attraction for sequential collapse is broad and stable under perturbation.

The available analytical record does not currently map that basin. Instead, it posits the attractor and then treats its existence as explanatory.

The correct order is the reverse:

- first demonstrate the basin
- then claim inevitability if the basin is large
- refrain from such claims if the basin is small or uncharacterized

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3.9 Where the Burden Properly Falls

The central question is not:

- whether collapse could happen
- whether collapse did happen
- whether collapse can be modeled

The question is:

Has it been shown that the specific observed form of collapse is a robust consequence of the known initial conditions, across realistic uncertainties, without fine-tuning?

If yes, inevitability is warranted. If no, it is not.

The remainder of the *Inventory* examines the models that purport to answer "yes."

Chapter 4 — Naive Bounds, Critical Regimes, and the Limits of Simple Models

Naive bounds do not deny complexity; they enforce it. A steel frame, however intricate, conserves energy and momentum. If observed behavior strains these bounds, the explanation must specify—without rhetorical shortcuts—how heterogeneity channels dynamics into a narrow outcome, not assume it does.

4.1 Relevance of Naive Models

Naive models do not explain complex structural failure. They do something simpler and more important:

they set outer limits on what is even remotely plausible

They answer questions of the form:

- How far can a falling block penetrate a comparable structure?
- How quickly can gravity-driven collapse proceed in the absence of added assumptions?
- How much resistance is required to produce arrest?

If observed behavior lies **outside** these naïve bounds, the explanation must invoke additional mechanisms. If observed behavior lies **inside**, the bounds do not constrain.

Either way, naive models are diagnostic. They define the **energy–momentum envelope** within which more elaborate accounts must live.

4.2 Impact Depth as an Upper-Bound Estimate

Treat the falling top portion as a single projectile of length L, density ρ_p, impacting a target of density ρ_t.

By simple momentum/energy arguments, the maximum depth of penetration into a comparably dense medium is on the order of the projectile length:

$\mathbf{s \sim L \cdot (\rho_p/\rho_t)}$

When $\rho_p \approx \rho_t$, the estimate is $s \sim L$.

Interpretation:

- a block of x floors cannot, in naive continuum mechanics, crush many multiples of x floors below it before its momentum is exhausted
- increasing resistance with depth **reduces** penetration below this already generous bound

This is not a full structural model. It is a **ceiling** on what gravity-driven crushing can accomplish without invoking critical-state dynamics, coordinated fracturing, mass shedding, or externally supplied energy.

4.3 Inelastic Collision and Arrest Tendencies

Now treat the interaction not as a continuum penetration problem but as a discrete inelastic collision between:

- a falling mass m_1 with velocity v
- a stationary mass _m_2 attached to the Earth

The post-impact velocity is:

$$\mathbf{v' = [m_1 / (m_1 + m_2)] \cdot v}$$

As m_2 grows with each engaged floor, v' rapidly decreases. Momentum is transferred downward; acceleration decays; arrest becomes increasingly likely unless resistance is vanishingly small.

Sequential progression without arrest therefore requires:

- persistent maintenance of substantial downward momentum
- continuing suppression of rising resistance
- preservation of fall-block coherence despite violent interaction

These are **constraints**. They are met only if the system occupies a narrow dynamical regime.

4.3.5 The Coefficient of Restitution Paradox

The analysis above assumes momentum is conserved during inelastic collision. But observed behavior presents a paradox when examined more carefully.

For velocity to **increase** between impacts (acceleration during descent):

$$\mathbf{v' > v}$$

This requires: $\mathbf{m_1/(m_1 + m_2) > 1}$

Which is **impossible** for any $m_2 > 0$.

For velocity to **remain constant** (free-fall descent, as approximately observed):

$$\mathbf{v' = v}$$

This requires: $\mathbf{m_1/(m_1 + m_2) = 1}$

Which implies $\mathbf{m_2 = 0}$ (zero effective resistance).

Yet observed behavior shows **near-constant descebt acceleration** over multiple stories. This is mechanically possible only if:

1. The **coefficient of restitution $\varepsilon \approx 1$** (nearly elastic collision), or

2. **Dynamic resistance is vanishingly small** ($m_2 \approx 0$ effectively), or
3. **Energy is added** to the system between impacts

All three contradict known structural behavior:

- Steel exhibits **highly inelastic** collision behavior ($\varepsilon \ll 1$)
- Documented column strengths satisfy **P_static >> mg**
- Energy dissipation occurs through:
    - Plastic buckling
    - Connection fracture
    - Material comminution
    - Air displacement

Resolution requires demonstration (not assertion) that: * Sequential failure produces **effective ε near unity** through some unidentified mechanism, **or** * Dynamic loading reduces resistance by **orders of magnitude** below static capacity, **or** * The collision model is fundamentally inappropriate for this regime

Neither has been demonstrated through ensemble analysis or validated physical testing.

The paradox is not proof of impossibility. It is **diagnostic evidence** that the mechanism occupies a **narrow, non-obvious region** of parameter space requiring explicit demonstration rather than assumed inevitability.

4.4 When Naive Models Normally Work

In ordinary engineering practice, naive models like the above:

- estimate pile-driving penetration
- evaluate impact cratering depth
- approximate collision outcomes
- assess preliminary arrest conditions

They succeed because most structural systems operate far from instability. In those regions:

- responses are quasi-linear
- local resistance approximates global behavior
- connection variability does not dominate

Upper bounds set by naive diagnostics are not just pedagogical; they are routinely conservative and reliable.

When naive bounds **fail spectacularly** in real systems, the failure itself is informative.

4.5 Critical Regimes: Where Simple Models Break

There exist domains where naive engineering models lose predictive power:

- Euler buckling

- dynamic fracture and branching crack fronts
- percolation and cascading failure
- avalanche release in metastable systems
- phase-transition analogs in continua
- progressive collapse near instability thresholds

These are **critical regimes**.

In them:

- global behavior is controlled by mode selection, not local stress
- small parametric changes produce large qualitative jumps
- nonlinearity amplifies variance
- conservation relations alone do not determine outcome

When an explanation requires invoking:

- crushing fronts
- compaction waves
- adiabatic heating
- critical-state continuum behavior

it is implicitly claiming the system entered such a regime.

That is a strong claim. It carries a burden:

show that this regime is reached generically, not only under finely tuned assumptions.

4.5.5 Metaphors of Propagation: Dominoes, Avalanches, and Chain Reactions

Descriptions of progressive collapse frequently invoke analogies such as dominoes, chain reactions, avalanches, or "houses of cards." These metaphors convey the intuition that once motion begins, continuation follows naturally. As heuristics, they are suggestive. As explanations, they are incomplete.

Each of these analogies corresponds to a specific class of dynamical system:

- **Dominoes** rely on pre-aligned geometry, low dissipation, and negligible reserve capacity.
- **Chain reactions** require local events that amplify energy or reduce resistance at each step.
- **Avalanches** occur in metastable systems already near a critical slope, with frictional resistance tuned close to failure.
- **Houses of cards** are deliberately unstable configurations with minimal redundancy.

In all cases, propagation depends not merely on initiation, but on the system residing within a **well-defined critical regime**. Outside that regime, disturbances arrest, dissipate, or localize.

Engineered steel structures differ from these analog systems in essential respects. They are designed with:

- significant reserve capacity,
- multiple parallel load paths,
- energy dissipation through plastic deformation,

- and redistribution mechanisms that tend to oppose synchronized failure.

Propagation metaphors therefore do not establish inevitability. They reframe the question: Does resistance decrease faster than destabilizing forces accumulate? That must be demonstrated across sequential stages, not assumed from analogy.

4.6 Porosity, Load Paths, and Zeroth-Order Intuition

High volumetric porosity ("mostly air") is sometimes cited as evidence that the towers offered limited resistance to downward motion. This intuition treats porosity as a proxy for structural weakness. On its own, it is not diagnostic.

In materials science, porosity generally reduces *material* strength, often approximated by relations of the form:

$$\boldsymbol{\sigma \approx \sigma_0 (1- \Phi)^n}$$

where Φ is porosity and n depends on material and microstructure. Such relations describe homogenized continua. They do not directly characterize the behavior of engineered structures, where resistance is governed by load paths, geometry, and force redistribution rather than bulk density.

Many highly porous systems — trusses, lattices, honeycombs, bone, and wood — achieve substantial load-bearing capacity by organizing material along stretching-dominated paths. In these systems, porosity reflects optimization for **specific strength**, not an absence of resistance.

The relevance of porosity to collapse dynamics therefore cannot be inferred from volume fraction alone. The same structural porosity that reduces self-weight also enables axial reserve capacity, redundancy, and redistribution — features that ordinarily act against progressive failure.

References to "mostly air" thus function as zeroth-order intuitions rather than mechanisms. They do not specify how engineered load paths lose resistance, how energy dissipation is bypassed, or why arrest would be generically suppressed once descent begins. If porosity is to play an explanatory role, its effect on structural resistance must be demonstrated quantitatively, not inferred from density alone.

4.7 Scale Arguments and the Square–Cube Misconception

Appeals to the square–cube law are frequently used to claim that large buildings are "naturally" prone to progressive collapse. This reflects a fundamental misunderstanding of how engineering differs from natural scaling.

4.7.1 The Square–Cube Law in Unengineered Systems

For geometrically similar structures scaled by factor *k*:

- **Volume (and mass)**: $\propto k^3$
- **Cross-sectional area (and strength)**: $\propto k^2$

- **Stress under self-weight**: $\propto k^3/k^2 = k$

This relationship explains why **unengineered systems**—animal skeletons, geological formations, or homogeneous solids—fail at large scales. A structure ten times larger experiences ten times the stress in its supporting members.

4.7.2 Why Engineered Structures Do Not Follow This Law

Buildings are not scaled animals or homogeneous solids. They are **coded, regulated, engineered systems** whose design parameters are deliberately sized with consequence of failure in mind:

- **Column cross-sections** are oversized relative to geometric scaling
- **Safety factors** increase with building height
- **Allowable stresses** are constrained by building codes
- **Load-path multiplicity** creates deliberate redundancy

Mass-to-strength ratios therefore follow **engineering scaling**, not naive geometric scaling.

4.7.3 Empirical Confirmation

This is why:

- The **Burj Khalifa** (828 m) stands
- The **Eiffel Tower** (300 m) has stood since 1889
- Large bridges do not routinely collapse under their own weight
- Tall towers do not typically buckle gravitationally
- Skyscrapers routinely survive earthquakes and fires without collapse

The WTC towers were designed following the same principle: column strength scaled to carry loads with large safety margins, specifically to **defeat** the square–cube limitation.

4.7.4 Implications for Progressive Collapse

The replication difficulty therefore **cannot** be attributed to scale effects.

If anything, larger structures should be **more stable** against progressive collapse due to:

- Higher absolute energy dissipation capacity
- Greater redundancy in load paths
- More deliberate engineering against catastrophic failure modes

The replication problem in this context is not explained by size.

It is explained—if it is explained—by **dynamics**, not geometry.

4.8 Dynamic Scaling and Adverse Growth of Demands

Dynamic processes do scale differently:

- kinetic energy ($E_k \propto m v^2$)
- momentum ($p \propto m v$)

- dissipation capacity scales with material strength and cross-sectional area

As structures grow, velocities achievable under gravity remain constant while participating mass increases. This can produce **adverse scaling in impacts**.

The correct question is therefore not:

- “Do large things fall more easily?”

but:

- **Does the observed collapse sit within the range predicted by scale-aware dynamic analysis across variance, or does it lie in a narrow band requiring parameter tuning?**

4.9 The Diagnostic Role of Paradox

Applied to the WTC collapses, naive bounds generate tensions:

- penetration-depth limits conflict with full-height collapse
- inelastic-collision slowing conflicts with sustained acceleration
- increasing mass conflicts with increasing comminution energy demand

These are not proofs of impossibility. They are **tensions requiring resolution**.

There are only two principled ways to resolve them:

1. show that naive models are being misapplied
2. show that the collapses resided in a critical regime where naive models are invalid

Both require **positive demonstration**. Neither is satisfied by narrative description alone.

4.10 What Naive Bounds Tell Us — and What They Don’t

They do not tell us:

- what mechanism occurred
- why the collapse progressed
- whether collapse was preventable

They do tell us:

- the observed behavior lies in a dynamically demanding region
- simple gravitational reasoning alone does not automatically recover it
- critical-regime assumptions appear necessary to eliminate paradoxes
- robustness, not plausibility, is the central unresolved variable

The fact that naive diagnostics generate tension does not settle the debate. It simply indicates that the burden shifts upward — toward high-fidelity modeling and open ensemble testing.

4.11 A Diagnostic Material Model: The Rate-Dependent Collapse Threshold

Consider a thought experiment that inverts familiar material behavior.

4.11.1 The Anti-Newtonian Solid

Standard materials exhibit predictable responses:

- **Newtonian fluids** (water, air): stress proportional to shear rate, $\sigma = \eta \dot{\gamma}$
- **Dilatant fluids** (cornstarch slurry): viscosity *increases* with shear rate—hit fast, acts solid
- **Structural steel**: exhibits strain-rate *hardening*—higher yield strength under rapid loading

Now consider the inverse: a material that:

- supports large static loads with high capacity
- offers vanishing resistance under rapid dynamic impact

Call this an **Anti-Newtonian Solid**. Its constitutive equation might take the form:

$\boldsymbol{\sigma = \eta \dot{\gamma}^{-k}}$ where $k > 1$

This produces:

- At low strain rates (slow loading): $\sigma \to \infty$ (high resistance)
- At high strain rates (rapid impact): $\sigma \to 0$ (progressive "mush")

4.11.2 Viscoplastic Buckling Extension

For columnar structures, couple this to effective modulus:

$\boldsymbol{E_{eff} = E_0 (1 + (\dot{\gamma} / \dot{\gamma}_0)^{-k})^{-1}}$

Then Euler buckling load becomes rate-dependent:

$\boldsymbol{P_{cr} = \pi^2 E_{eff} I / L^2}$

Under slow gravity: $E_{eff} \approx E_0$ → normal capacity
Under impact ($v \approx \sqrt{(2gh)} \sim 15$ m/s): $\dot{\gamma} \gg \dot{\gamma}_0 \to E_{eff} \to 0 \to$ catastrophic buckling

4.11.3 What This Model Does

It does not represent real steel. Real structural steel exhibits:

- strain-rate hardening (opposite behavior)
- energy absorption through plastic deformation
- fracture toughness that scales with cross-section

It does represent the implicit assumptions required for sequential collapse to proceed as described:

- robust under service conditions (✓ observed: towers stood for decades)
- minimal resistance once dynamic descent begins (✓ asserted: "inevitable progression")
- threshold velocity separating regimes (✓ implied: initiation triggers runaway)

(see also: **3.5: The Stability-Instability Razor**)

4.11.4 Diagnostic Function

This zeroth-order model clarifies the burden on inevitability claims:

If ordinary structural steel behaved according to:

$\boldsymbol{\sigma = \sigma_0 (\dot{\gamma} / \dot{\gamma}_{ref})^n}$ where $n > 0$ (rate hardening)

then rapid impacts would *increase* resistance, favoring arrest.

For progression to be generic, the system must instead exhibit:

$\boldsymbol{\sigma_{eff} \propto \dot{\gamma}^{-k}}$ (inverse rate dependence)

This is achievable through combinations of:

- synchronized thermal weakening
- connection failure thresholds
- geometric nonlinearity
- coordinated redistribution suppression

But these are not generic properties—they are *conditional outcomes* requiring specific structural states.

4.11.5 Energy Implications

Under the Anti-Newtonian model, energy dissipation per story:

$\boldsymbol{W_d = \int \sigma \, d\varepsilon \approx \eta \, \dot{\gamma}^{-k} \, \varepsilon_{max}}$

As impact velocity increases ($\dot{\gamma} \uparrow$), dissipation *decreases*—consistent with observed rapid descent.

But real steel dissipates *more* energy under dynamic loading, not less. The tension is resolved only if:

- thermal weakening reduces σ_0 dramatically, or
- connection failures bypass plastic dissipation, or
- comminution absorbs energy via different pathways

Each requires demonstration, not assumption.

4.11.6 The Satirical Core

The Anti-Newtonian Solid is, of course, a **reductio**: it shows what material properties would make the claimed mechanism trivially inevitable.

Real structures do not behave this way.

Therefore, claims that observed behavior follows “generically” from gravity and fire must either:

1. Show that fire+damage creates effective Anti-Newtonian conditions broadly across parameter space, or
2. Retract from “inevitable” to “plausible under specific conditions”

The first requires ensemble modeling. The second is honest epistemic positioning.

Chapter 5 — Energy Scales, Impact Comparisons, and Diagnostic Tensions

Naive bounds establish what gravity alone cannot easily achieve. Energy-scale comparisons add precision: they quantify how much energy was applied, where it went, and why structurally similar inputs produced drastically different outcomes. This chapter examines those contrasts.

5.1 Why Compare Energy Scales at All

Energy comparisons do not explain collapse mechanics. They perform a narrower function:

they test internal coherence of claimed mechanisms

If two events differ drastically in consequence while similar or larger energy inputs are involved, explanation must identify:

- *where* energy went,
- *how* it was dissipated,
- *why* qualitatively different structural responses occurred.

Without this, accounts become narrative rather than mechanistic.

5.2 Horizontal Impact: Aircraft Strikes as a Structural Disturbance

The aircraft impacts delivered kinetic energies on the order of gigajoules. The loading was:

- high-velocity,
- localized,
- largely horizontal,
- accompanied by fragmentation and fuel dispersal.

Observed global structural response:

- transient lateral sway,
- damped oscillation within design expectations,
- no immediate loss of global stability.

Despite intense local damage and fires, the structures remained standing for extended periods.

The contrast is not energy magnitude but failure topology. Horizontal impact did not trigger a failure pathway with positive feedback; vertical progressive failure did.

This establishes a simple empirical fact:

> Large energy input alone is insufficient to cause immediate global collapse in tall framed-tube structures.

Any adequate account of the subsequent global collapse must therefore identify **the specific mechanism by which later, smaller incremental energy inputs produced complete failure**.

5.3 Quantitative Energy Asymmetry

The horizontal–vertical contrast can be quantified using energy estimates from NIST and Bažant's models.

Aircraft impact (WTC 1):

- Mass: ~150,000 kg
- Velocity: ~470 mph (~210 m/s)
- Kinetic energy: KE = ½mv² ≈ **3.3 GJ**

Observed response:

- Transient sway amplitude ~1/3 of design envelope[NCSTAR-1, p. 182]
- Damped oscillation with period nearly equal to undamaged structure
- Global stability maintained for 102 minutes

First story drop (Bažant's model):

- Upper block mass: 58,000 tonnes
- Drop height: 3.7 m (one story)
- Gravitational energy: PE = mgh ≈ **2.1 GJ**[BAZANT-405]

Observed outcome:

- Initiation of progressive collapse
- Descent through ~85 undamaged stories
- Total structural destruction

Diagnostic observation:

A larger energy input (3.3 GJ) delivered horizontally—where the structure is designed to flex—was absorbed without global failure.

A smaller energy input (2.1 GJ) delivered vertically—where the structure has massive reserve capacity—allegedly initiated total collapse.

This asymmetry does not constitute a contradiction. It identifies that:

- **Loading direction** and **failure topology** dominate over energy magnitude alone
- Horizontal impact did not couple into a self-reinforcing failure mode
- Vertical progression did

The question is not whether gravity provides sufficient total energy (it does), but **by what mechanism vertical increments couple into coordinated collapse while larger horizontal inputs do not**.

5.4 The Horizontal–Vertical Outcome Contrast

Here lies the diagnostic tension:

- larger total energy input (aircraft impact) produced **no global collapse**
- smaller incremental vertical inputs (floor-to-floor descent) produced **total structural destruction**

This contrast does not imply contradiction. It implies that:

- **loading mode**,
- **time history**,
- **failure topology**,
- **momentum transfer pathways**

dominate outcomes.

A coherent explanation must therefore exhibit **mechanism-level clarity**:

- how the system transitioned from demonstrated robustness to runaway progression,
- why dissipation pathways that prevented collapse earlier did not do so later,
- why progressive failure suppressed otherwise expected asymmetries (tilt, hang-up, partial collapse).

Merely invoking "gravity did the rest" leaves the mechanism unspecified.

5.5 Momentum Transfer and Dynamic Amplification

Dynamic amplification is often cited as the missing ingredient.

The core claim:

- once motion begins, momentum grows,
- each impact raises local demand,
- resistance falls behind energy input,
- runaway progression follows.

This is plausible in abstract form.

It becomes sufficient only when four additional statements are demonstrated:

1. **progression remains axial without enforced symmetry**
2. **falling mass remains coherent under violent interaction**
3. **rising resistance does not overtake increasing mass**
4. **arrest probability remains negligible across realistic variance**

Each is empirical. None are guaranteed by amplification alone.

5.6 Dissipation Pathways and the Accounting Problem

Total gravitational energy during collapse is large.

What matters is partinioning:

- plastic deformation,
- fracture and comminution,
- ejection of material,
- heating of air and dust,
- seismic coupling,
- acoustic release.

Statements such as “gravity supplied sufficient energy” may be correct but are non-diagnostic.

The relevant question is:

> **Does the proposed mechanism partition energy in a way that produces the specific observed pattern of acceleration, symmetry, and material pulverization?**

That requires:

- modeling of crack propagation and comminution,
- structural breakup dynamics,
- air–dust interaction,
- momentum exchange in non-rigid bodies.

Where modeling exists, it is typically calibrated, not variance-tested.

5.7 The Non-Intuitive Ordering of Difficulty

Intuition suggests:

- global collapse of a skyscraper is extremely difficult,
- lateral robustness is designed and tested,
- axial runaway failure is atypical compared to lateral stability concerns.

The observed ordering reverses this intuition:

- massive lateral energy inputs were survived,
- modest vertical increments produced total failure.

This is not contradiction. It is a **diagnostic inversion**.

It requires mechanism-level explanation, not narrative restatement.

5.8 Momentum Transfer Under Maximally Permissive Asssumptions

Even under collapse-favorable assumptions—frangible columns, rigid upper block, no lateral DOFs—sequential inelastic collisions impose a strong dissipative constraint.

Szuladziński (2012)[SZULADZINSKI]:

- models stories as discrete masses merging plastically
- neglects column resistance
- includes only momentum exchange losses

Result:

> ≈ one-third of total gravitational potential is dissipated by collisional damping alone.

Minimum descent times then approach **≈15 s** even under idealized conditions, lengthening markedly as resistance terms are reintroduced.

This result is lower-bounding rather than predictive; it constrains possible acceleration trajectories rather than determining actual ones.

Implication:

> **approaching observed times requires simultaneously suppressing both structural resistance and inherent collisional dissipation,** a combination that occupies an extreme corner of parameter space.

This does not prove impossibility. It identifies a structural incompatibility among:

- rapid descent,
- sequential accretion,
- full-height progression.

5.9 What Energy Comparisons Establish

They do not:

- prove or disprove any hypothesis,
- attribute intent,
- specify cause.

They do:

- require energy-partitioning explanations,
- expose tensions between robustness and inevitability claims,
- demand explicit mechanisms for mode selection,
- highlight the non-triviality of the observed progression.

The key point is simple:

> The joint outcome of rapid, near-axial, global collapse with extensive comminution under heterogeneous conditions remains physically demanding. Energy magnitudes alone do not resolve that demand.

Chapter 6 — Models of Inevitability: Calibration, Validation, and Circularity Risks

6.1 What "inevitability" actually requires

A claim of inevitability is stronger than a claim of plausibility.

- *Plausible* means: an account is consistent with known laws and parameters.
- *Inevitable* means: across realistic variability, the same outcome occurs with high probability.

To justify inevitability, an explanation must show that:

1. the observed outcome occupies a **large basin of attraction**, and
2. nearby states in parameter space converge to that same outcome.

A model that reproduces one observed case is therefore insufficient. Inevitability is demonstrated not by fit, but by **robust recurrence under variance**.

6.2 Calibration is not a defect — but it is not validation

All serious models of unique historical events are calibrated. That is normal scientific practice.

What is at issue here is not calibration itself, but the **confounding of calibration with validation**.

Calibration:

- adjust uncertain parameters,
- match observed behavior,
- identify ranges compatible with data.

Validation:

- specify the model before observing new data,
- predict outcomes not used in calibration,
- survive independent tests.

When the same dataset is used to:

- tune free parameters and
- claim the success of the tuned model,

calibration and validation collapse into a single step. That is where circularity risk arises.

6.3 Characteristic properties of "proof-of-collapse" models

Models explicitly developed to show that collapse progression must occur share certain structural features:

- constrained degrees of freedom (often one-dimensional vertical motion),
- rigid or quasi-rigid upper blocks,

- homogenization of discrete structural elements,
- simplified load–displacement laws,
- parameters selected to favor progression,
- symmetry enforced or inherited from boundary conditions.

None of these features are illegitimate. They are recognizable as **idealizations**.

What follows from them, however, is crucial:

> A model built to show that collapse proceeds cannot, by construction, discover arrest dominated by unsymmetrical, multimode behavior it excludes.

It evaluates sufficiency under the assumptions it encodes. It does not evaluate inevitability under real-world variability.

6.4 The circularity pattern

A characteristic reasoning loop is common across such analyses:

1. collapse is observed,
2. a model is designed to demonstrate collapse progression,
3. free parameters are chosen or tuned to match observed timing and behavior,
4. the resulting match is cited as evidence that collapse was inevitable.

Formally, the same empirical record plays two roles:

- constraint for parameter selection, and
- test for explanatory success.

This is not fraud. It is a **structural epistemic limitation**. It produces strong **retrodiction**, not independent prediction.

6.5 Limits imposed by boundary choices

When:

- lateral motion is suppressed,
- block breakup is neglected,
- multiple failure fronts are excluded,
- local connection variability is smeared into continuum resistance,

the resulting model space excludes:

- toppling,
- partial collapse,
- asymmetric arrest,
- competing descent modes.

Therefore, when such models report that collapse progresses rather than arrests, the result is:

> a statement about what happens in the reduced model space, not about the full dynamics of real structures under variance.

Inevitability claims derived from such restricted models rely on extending their conclusions beyond the domains they actually explore.

6.6 The missing quantity: arrest frequency under variance

The relevant unanswered question is simple:

> Across realistic variability of input parameters, how often does the modeled structure arrest, partially collapse, or fail asymmetrically?

This requires:

- large ensemble runs,
- stochastic parameter distributions,
- no symmetry constraints,
- open reporting of arrest rates and divergence cases.

What currently exists in the public record largely consists of:

- single trajectories,
- parameter sweeps guided by observed outcomes,
- high-fidelity reconstructions tuned to match video evidence.

These demonstrate that collapse *can* be represented in models. They do not establish that the observed collapses occupy a **broad, stable basin of attraction**.

6.7 Calibration transparency and sensitivity

A nontrivial proportion of model parameters affecting progression are:

- not directly measured for the WTC structures,
- inferred from analogous systems,
- adjusted within physically “reasonable” bounds,
- sensitive to assumptions about insulation loss, connection behavior, and heat histories.

Two requirements follow if inevitability is to be asserted:

1. parameter choices and sensitivity must be fully transparent, and
2. ensemble statistics must be reported across the ranges of uncertainty.

When transparency or ensemble reporting is absent, claims of robustness rest on **unexamined fragility**.

6.8 What the existing modeling record does show

It shows that:

- progressive gravity-driven collapse is mechanically plausible,
- dynamic amplification matters,
- idealized models can reproduce aspects of observed descent,
- calibrated simulations can visually match large portions of the event.

These are nontrivial achievements.

What it does not yet decisively show is that:

- progression is generic rather than finely conditioned,
- symmetry is naturally selected rather than imposed,
- arrest is rare rather than pruned away by modeling choices,
- the observed outcome recurs broadly across uncertainty.

Those are the conditions necessary for inevitability claims.

6.9 Model Plurality and the Limits of "Generic" Inevitability Claims

Claims of post-initiation inevitability are further constrained by the existence of **multiple peer-reviewed mechanical frameworks** that model the collapse sequence using different "generic" assumptions.

Representative examples include:

- **Bažant / NIST:** one-dimensional rigid-block, gravity-driven progressive collapse [BAZANT-405, NCSTAR-1, BAZANT-466, BAZANT-476, BAZANT-499, BAZANT-585, BAZANT-625, BAZANT-EPN];
- **Seffen:** propagating instability models treating collapse as a wave-like failure mode[SEFFEN];
- **Usmani:** global fire–structure interaction emphasizing thermally induced system-level forces[USMANI];
- **Szuladzinski:** energy-dissipation–focused analyses emphasizing column resistance and collisional losses[SZULADZINSKI].

These differences are not minor parametric adjustments. They reflect fundamentally different physical pictures:

Seffen treats collapse as a propagating instability requiring specific wave conditions—still "generic" in his view, but with stricter mathematical constraints than simple energy comparison. Usmani emphasizes that initiation mode (thermal expansion laterally compromising the core) determines progression character, challenging the decoupling of initiation from dynamics. Szuladzinski and Korol directly dispute Bažant's energy calculations, arguing that column resistance and momentum dissipation are significantly higher, shrinking the "margin" for inevitable progression.

These approaches differ in how they treat energy dissipation, symmetry, resistance evolution, and the coupling between initiation and progression. All are mechanically conventional; none invoke non-standard physics.

The relevance of this plurality is methodological rather than adjudicative. When multiple, mathematically distinct models—each employing simplified but defensible assumptions—can account for aspects of the observed outcome, the observation does not uniquely select any one of them as a proof of inevitability. Instead, the outcome is **underdetermined** by the available modeling record.

This does not imply that any of these frameworks is incorrect, nor that collapse was unlikely. It implies only that inevitability cannot be established by appeal to a single reduced-order model whose conclusions depend on specific idealizations, particularly in the absence of ensemble analysis across realistic uncertainty.

Accordingly, the existence of competing "generic" models reinforces the central distinction emphasized throughout this document: calibrated models demonstrate **plausibility**, while claims of **inevitability** require demonstrated robustness independent of modeling choices. That standard has not yet been met.

6.10 The appropriate methodological conclusion

The scientifically disciplined position is narrow and precise:

- calibrated models establish **plausibility**,
- inevitability requires **robustness across variance**,
- robustness has not yet been demonstrated to the standard normally invoked for strong closure claims.

No alternative mechanism is asserted. No counter-narrative is assumed.

The conclusion is methodological:

> The current modeling record justifies "can collapse under these conditions," but it does not yet justify "had to collapse in this way."

That difference is not rhetorical. It is the boundary between **explanation** and **epistemic closure**.

6.11 The Stated Aim: Proving "Must" and "Inevitable"

The modeling literature does not conceal its aim: to establish that progressive collapse was inevitable once initiated, driven by gravity alone. This intent is stated plainly and repeatedly, framing the analyses as demonstrations of necessity rather than explorations of possibility. From Bažant and Zhou (2002):

> "Since we are not attempting to model the details of the real failure mechanism but **seek only to prove that the towers must have collapsed and do so in the way seen**…"

In the accompanying discussion:

> "The wedging was not considered in the analysis because **the stated aim was to prove that the towers must have collapsed**. For that purpose, the most optimistic assumptions about the structure resistance had to be made, and the assumption of wedging would not be of that kind."

NIST builds on this foundation, limiting detailed simulation to pre-initiation events while deeming progression self-evident:

> "The specific objectives were: 1. Determine **why and how WTC 1 and WTC 2 collapsed** following the initial impacts of the aircraft and why and how WTC 7 collapsed."
> *— (NCSTAR 1, p. xxxix)*

Yet:

> "The focus of the investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower. For brevity in this report, this sequence is referred to as the 'probable collapse sequence,' although it **includes little analysis of the structural behaviour of the tower after the conditions for collapse initiation were reached and collapse became inevitable**."
> *—(footnote on p. xxxvii)*

And again:

> "The focus of the Investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower. For brevity in this report, this sequence is referred to as the "probable collapse sequence," although it **does not actually include the structural behavior of the tower after the conditions for collapse initiation were reached and collapse became inevitable.**"
> *—(footnote on p. 82)*

Bažant and Verdure (2007) reinforce this, tying it to a specific criterion while dismissing alternatives:

> "Regardless of the load capacity of the columns, there is no way to deny the inevitability of progressive collapse driven by gravity alone if this criterion is satisfied (for the World Trade Center it is satisfied with an order-of-magnitude margin)."
>
> "Therefore, no further analysis has been necessary to prove that the WTC towers had to fall the way they did, due to gravity alone. However, a theory describing the progressive collapse dynamics beyond the initial trigger, with the WTC as a paradigm, could nevertheless be very useful for other purposes, especially for learning from demolitions. It could also help to clear up misunderstanding (and thus to dispel the myth of planted explosives)."
>
> "The subsequent progressive collapse was not simulated at NIST because its inevitability, once triggered by impact after column buckling, had already been proven by Bažant and Zhou's (2002a) comparison of kinetic energy to energy absorption capability."

> “Some critics have been under the mistaken impression that collapse cannot occur if (because of safety factors used in design) the weight mg of the upper part is less than the load capacity F_0 of the floor. This led them to postulate various strange ideas (such as “fracture wave” and planted explosives). However, the criterion in Eq. (5) makes it clear that this impression is erroneous. If Eq. (5) is violated, there is (regardless of F0) no way to deny the inevitability of progressive collapse driven only by gravity."
>
> “If the total (internal) energy loss during the crushing of one story (representing the energy dissipated by the complete crushing and compaction of one story, minus the loss of gravity potential during the crushing of that story) exceeds the kinetic energy impacted to that story, collapse will continue to the next story. This is the criterion of progressive collapse trigger [Eq. (5)]. If it is satisfied, there is no way to deny the inevitability of progressive collapse driven by gravity alone (regardless of by how much the combined strength of columns of one floor may exceed the weight of the part of the tower above that floor).”[BAZANT-466]

The logical structure is clear:

- Adopt maximally collapse-favorable assumptions (e.g., frangible columns, rigid upper block, negligible comminution energy).
- Show that under these assumptions, gravitational energy exceeds resistance.
- Conclude that collapse was therefore inevitable—“doomed,” “must have collapsed,” “had to fall”—*regardless of whether those assumptions reflect physical reality or variance.*

These statements elevate calibrated, assumption-bound models to proofs of inevitability. The lever turns here: “Inevitable” implies a dynamical necessity that holds across realistic uncertainties—not a conditional outcome under optimistic simplifications. Where models are built to prove “must” via tuning (e.g., selecting parameters like β, γ, κ_out to match descent without exploring arrest under variance), they demonstrate compatibility, not necessity. The epistemic demand remains: Show the basin for “must” is broad, or retract to “could.”

Later Bažant papers (2008–2017) refine component mechanisms and respond to select criticisms, but they do not address the central issue assessed here: the claim of post-initiation inevitability is still advanced without basin mapping, or robustness demonstration under realistic variance.

Chapter 7 — Evidentiary Gaps and Epistemic Asymmetry

7.1 Method is itself evidence

Scientific inference does not rely only on what is measured. It also relies on **what is preserved, tested, and made available for replication**.

Where evidence is fragile, method is decisive.

Three questions are therefore legitimate:

- What physical evidence was preserved?

- What discriminating tests were performed?
- What opportunities for resolution were foregone?

They do not assign motive. They evaluate **epistemic hygiene**.

7.2 The evidence that no longer exists

Large fractions of:

- recovered structural steel,
- connection assemblies,
- fire-affected members,

were **recycled before full forensic cataloguing and testing** [KNOWLES, KOHN, MANNING, CHINA-BAOSTEEL].

This limited later possibilities to:

- map failure modes member-by-member,
- conduct systematic metallurgical testing,
- perform comparative residue analysis,
- physically reassemble critical regions.

> Motivation is not assessed here. What matters is the **irretrievable information loss**.

7.3 Untested alternative signatures

Standard investigative protocols in structural failures and fire/explosion analysis normally include [NFPA-921, PETROSKI]:

- residue testing where multiple mechanisms are conceivable,
- preservation of fracture surfaces,
- archiving of critical members,
- chain-of-custody documentation for later scrutiny.

In this case, testing regimes that could have **distinguished among mechanisms** were often not undertaken on the grounds that certain outcomes were already deemed unnecessary to consider.

This converts conclusion into premise:

> When alternative mechanisms are excluded **before** discriminating tests, the result reflects assumption rather than test outcome.

7.4 Asymmetry in doubt

A recurrent pattern emerges:

- uncertainty counts **against** unapproved hypotheses,
- uncertainty counts **for** the accepted one.

Examples include:

- absence of residue → cited as absence of alternative mechanism while testing for residues was limited or foregone;
- non-reproduction → cited as lack of expertise while independent reproduction was not materially enabled;
- evidence loss → treated as administratively necessary while its epistemic cost was not acknowledged.

The asymmetry is not subtle:

> doubt is applied asymmetrically.

One methodological approach is asked to meet **experimental standards under missing evidence**, another approach is allowed to rest on **plausibility and authority** despite the same evidentiary gaps.

That asymmetry is a methodological flaw *regardless* of ultimate conclusions.

7.5 Lost opportunities for closure

The following would have materially increased epistemic clarity:

- comprehensive preservation of structural steel,
- systematic destructive testing and microanalysis,
- standardized residue screening,
- public access to modeling inputs and ensembles,
- independent reproduction programs,
- explicit falsifiability criteria.

Most of these no longer exist as possibilities. They were foreclosed not by physics, but by procedural choices.

The result is not mystery. It is **avoidable opacity**.

7.6 What follows — and what does not

This chapter supports **one** conclusion only:

> Where evidence is disposed of or untested, uncertainty increases, and claims of finality weaken.

It does **not** support:

- assertions of alternative mechanisms,
- identification of responsible actors,

- declarations of impossibility.

It supports a methodologically modest position:

> In the presence of evidentiary gaps created by investigative choices, strong claims of inevitability should be regarded as unearned.

Chapter 8 — A Positive Research Program

The purpose of this document is not to preserve uncertainty. The purpose is to **make resolution possible.**

Historical uniqueness does not prevent validation; it shifts it toward component phenomena and adjacent reference classes.

A constructive research program follows directly from the preceding analysis. It aims to determine whether the observed collapses are:

- robust consequences of impact and fire, or
- outcomes that occupy a narrow, fine-tuned region of behavior.

If inevitability is correct, this program will find it. If it is not, this program will show the limits of current models.

The program contains four components.

8.1 Transparency and Reproducibility

Required steps:

- publication of model inputs, source code, and resistance curves
- assumption documentation
- publication of parameter provenance and sensitivities
- release of arrest statistics rather than only successful runs
- independent reproduction of key simulations by unaffiliated groups

Outcome:

- if results reproduce across groups → confidence increases
- if they do not → sensitivity and fragility must be explained

This is the minimum standard in any other mature quantitative field.

8.2 Ensemble Modeling Across Variance

Single "hero simulations" are non-diagnostic with respect to robustness.

What matters is **frequency** of the observed outcome.

Research target:

> Distribute input uncertainties realistically and run large ensembles.

Variables include:

- damage distribution
- insulation loss uncertainty
- fire evolution variability
- connection strength distributions
- initial asymmetries and eccentricities

Measured quantities:

- probability of global collapse
- probability of arrest
- probability of asymmetric/tipping outcomes
- dispersion of collapse duration and symmetry metrics

Interpretation:

- high recurrence ⇒ robustness
- low recurrence ⇒ fine-tuning

Either result advances knowledge. No outcome is disallowed.

8.3 Outcome-Space Mapping

The observed collapse corresponds to a location in multidimensional parameter space defined by duration, symmetry, completeness, and fragmentation.

The task is to **map neighborhoods** in that space.

Program goals:

- identify basins of attraction
- identify boundaries of arrest versus progression
- identify competing dynamical modes
- determine where the observed outcome lies in that topology

Key diagnostic question:

> Is the observed collapse inside a wide basin, or on a narrow ridge?

8.4 Laboratory and Physical Modeling

Physical testing is expensive but not conceptually exotic.

Candidates include:

- scaled connection failure tests under dynamic loading
- column buckling and fracture energy characterization
- stacked-mass progressive collapse analogs with variance
- granular comminution and energy partitioning studies

Desired outcomes:

- independent validation of resistance curves used in models
- empirical arrest probabilities
- constraints on comminution energy budgets

The goal is not to recreate the towers. The goal is to **constrain the parameter space in which models operate.**

8.5 What Would Count as Resolution

The program is explicitly falsifiable. Both outcomes—robust recurrence or fine-tuned sensitivity—are acceptable scientific results.

Resolution in favor of robustness

The inevitability claim would be strengthened if:

- ensemble models with realistic variance
- open inputs and independent reproduction
- empirically constrained resistance functions

show that:

- rapid, near-axial, non-arresting progression
- arises frequently and stably
- across broad parameter ranges

This would justify the term **“robust consequence.”**

Resolution in favor of fine-tuning

Conversely, inevitability would weaken if:

- outcomes require narrow tuning,
- collapse arrests under modest variance,
- symmetry requires constraints,
- parameter sensitivity is extreme.

That would justify the term **“critical regime near threshold.”**

Either outcome refines knowledge. Neither predetermines mechanism.

8.6 What This Program Does Not Do

It does not:

- advocate any alternative mechanism
- seek to confirm demolition hypotheses
- require impossible recreations of full-scale towers
- rest on insinuation

It does one thing:

> articulate the experimental and modeling pathway by which the question of robustness versus fine-tuning can be settled to scientific standards.

Closing

The refusal to pretend to know is not a destination.

It is the beginning of a **program of disciplined inquiry**.

The path forward is clear:

- transparency,
- ensembles,
- empirical constraints,
- outcome-space mapping.

If inevitability is true, this program will reveal it. If it is not, this program will reveal that too.

Either way, science wins.

Coda — On Epicycles of Inevitability

The central claim of this document is narrow:

- collapse occurred,
- collapse is physically possible,
- **inevitability has not been demonstrated.**

Nothing in this analysis requires — or defends — speculative alternatives. It does not endorse explosives, “space lasers,” or any other mechanism. Those claims lie outside its scope.

What is at issue here is **not what happened**, but **how we claim to know**.

The history of science is littered with confident systems built on:

- calibration mistaken for validation,
- theory-saving patches,
- appeals to consensus in lieu of experiment,
- destruction or neglect of contradictory evidence.

Their names are familiar: **epicycles, miasma, phlogiston**.

The lesson is not cynicism. It is discipline.

Claims of physical inevitability must earn their status by:

- transparency,
- reproducibility,
- robustness across variance,
- willingness to be proven wrong.

Where replication is difficult, variability high, sensitivity strong, and evidence incomplete, **closure is premature —** regardless of which hypothesis one prefers.

This critique targets explanations, not explainers. The goal is better science, not blame.

Refusing to pretend to know is not weakness. It is the core strength of scientific reasoning.

The correct position in such domains is neither credulity nor dogmatism, but disciplined openness:

> The explanation may be correct. It may even be the simplest. But the standards by which science judges inevitability have not yet been met.

Until they are, inquiry remains legitimate.

And that is not a scandal.

It is science.

Appendix: Derivations and Method Notes

This appendix expands the arguments in the main document with explicit formulations, assumptions, and diagnostic implications. Its purpose is strictly methodological:

- to show how each claim cashes out mathematically or physically
- to separate assumptions from results
- to identify where robustness has and has not been demonstrated

No additional hypotheses are introduced. Where data are uncertain or contested, this is stated directly.

Notation

For clarity, a small number of symbols are used consistently throughout this appendix:

- **O –** observed joint outcome vector of the collapse
- **T –** total fraction of structural loss
- **S –** axial symmetry metric (normalized centroid deviation)
- **V –** descent velocity normalized to free-fall
- **C –** comminution metric (inverse characteristic fragment size)

- $\mathscr{B}$ – basin of attraction for a given dynamical outcome (e.g., total progression)
- **S_B** – basin volume fraction; measure of robustness of $\mathscr{B}$ under parameter variance
- **B_S** – basin stability bound; perturbation distance at which robustness drops below tolerance
- **S_{bb}** – basin entropy; degree of unpredictability of basin boundary
- **m, g, h** – mass, gravitational acceleration, characteristic drop height
- **E_g** – gravitational potential energy
- **E_b** – energy dissipated by buckling and plastic deformation
- **E_c** – energy associated with comminution and surface creation
- **P_s** – static capacity of a structural element or story
- **P_d** – dynamic demand under impact or progression loading

Numerical values are **order-of-magnitude indicators**. The argument concerns **structure**, not precision.

Note 1 — The Replication Problem (Physical Difficulty)

1.1 Statement of the Phenomenon

The joint outcome is defined from observable quantities:

- total descent time
- acceleration profile
- symmetry of descent
- extent of structural loss
- degree of comminution

Let **O** denote the joint outcome vector. Approximate components include:

- (T) — fraction of global structural loss
- (S) — axial symmetry (normalized centroid deviation)
- (V) — ratio of observed descent rate to free fall
- (C) — inverse fragment-size metric (comminution)

The diagnostic feature is not any single component, but the **covariance** of high (V), high (T), high (S), and high (C). Many structural failure modes produce one or two of these; the conjunction is rare and requires mechanism.

> *Measurement-constrained description of the phenomenon to be explained.*

1.2 Extraordinary Difficulty of Reproduction

The replication difficulty is grounded in basic energy bookkeeping and empirical experience with physical models.

Gravitational potential available: $\mathbf{E_g = mgh}$

Energy dissipation channels include:

- plastic column buckling $\mathbf{E_b = \int P, dz}$
- fracture and tearing
- comminution (surface creation) $\mathbf{E_c \propto \Delta A}$

In simplified models built to **favor** progression (restricted DOF, symmetry imposed, negligible comminution), arrest or partial progression frequently occurs unless strengths are tuned to carried mass.

This is a diagnostic observation:

> reproducing the joint outcome requires parameter selection, constraint enforcement, or boundary conditioning.

Difficulty is empirical; it does not decide mechanism, but it constrains claims of inevitability.

1.3 Minimal Sufficiency Test

The minimal replication challenge is formulated as:

1. construct a multi-story gravity-loaded structure
2. remove or isolate the top fraction
3. impose downward impact
4. record
    - descent profile
    - symmetry
    - arrest frequency

No requirement for geometric fidelity is implied. What matters is whether **rapid, symmetric, non-arresting progression** occurs **robustly under variance**.

Let

$\mathbf{P_{obs} = N_{observed\text{-}like} / N_{trials}}$

If *P_obs* is small without tuning, the outcome occupies a narrow region of outcome space. Robust inevitability requires *P_obs* high across variance.

A clearly falsifiable research program.

Uncertainty and Error Sources

All inferences in this document are conditioned on several unavoidable sources of uncertainty: (i) ***measurement noise*** *in kinematic reconstruction from video records (frame-rate limits, parallax, occlusion), (ii)* ***model error****, including idealizations* *necessary for tractable simulation (dimensionality reduction, constitutive simplifications, boundary condition assumptions), and (iii)* ***structural heterogeneity****, including undocumented variations in material properties, connection behavior, prior damage, and fire exposure. These uncertainties do not invalidate analysis; they define its* ***confidence bounds****. Claims of inevitability require robustness* ***across*** *these uncertainties. Conversely, where outcome sensitivity to such uncertainties is high, the corresponding claims should be regarded as provisional.*

Note 2 — Sequential Failure, Reserve Capacity, and Fine-Tuning

2.1 The Sequential Failure Constraint

Required conditions per floor:

1. sufficient static capacity with safety margin
2. insufficient dynamic capacity under impact

Let

- $\mathbf{P_s}$ — static capacity
- $\mathbf{P_d}$ — dynamic demand

Then sequential progression requires:

$\mathbf{P_s > P_{service}}$ **AND** $\mathbf{P_d > P_s}$

This is a mutual constraint. Deviations in either direction lead to:

- premature global failure
- arrest
- asymmetric collapse

Necessary condition for idealized progression models.

2.2 Default System Response Without Tuning

Structural frames exhibit:

- redundancy
- load redistribution
- local hinge formation
- disorder in strength and damage

Network and fiber-bundle analogs show [NEWMAN, STROGATZ]:

- local load sharing → localization and arrest
- equal load sharing → global progression

Therefore, any model that yields smooth progression must justify the **coordinating mechanism** that converts a heterogeneous real frame into an effectively equal-load-sharing system.

Qualitative but widely supported in progressive collapse mechanics.

2.3 Vertical Reserve Capacity and Basins of Attraction

Tall buildings are governed primarily by **lateral** limits (P–Δ effects, drift limits) KRAUTHAMMER. Satisfying lateral requirements generates:

- large **axial reserve**
- redundancy
- alternative load paths

Thus the natural basin of attraction includes:

- partial collapse
- tilt and rotation
- load redistribution
- arrest

Rapid, symmetric axial progression occupies a narrower basin requiring suppression of stabilizing modes across many stories.

design-logic inference; robustness must be demonstrated, not assumed.

2.4 Quantitative Measures of Basin Narrowness

Terms like “fine-tuned,” “razor sharp,” or “narrow basin” refer to dynamical properties where outcomes are sensitive to small perturbations in parameter space, not robust attractors. In progressive collapse models, these can be quantified without assuming intent, using methods from dynamical systems applied to structural analogs (e.g., high-dimensional failure networks).

- **Basin Volume Fraction (Stability Measure)**:
  The size of the basin of attraction $\mathscr{B}$ for total collapse is the fraction of initial conditions or parameters leading to that outcome:

  $$\mathbf{S_B = Vol(\mathscr{B} \cap X_P) / Vol(X_P)}$$

where X_P is the perturbation region (e.g., variance in fire damage, connection strength ±20%). A “narrow basin” has low S_B (e.g., <0.1), meaning collapse occurs in <10% of realistic ensembles. Monte Carlo sampling estimates this: Sample $n = 1000$ runs; if progression happens in <100, the basin is narrow, prone to arrest under variance.

- **Basin Stability Bound (Distance-Based)**:
  Measures the maximum perturbation distance d before stability drops below tolerance t (e.g., $t=0.9$ for 90% progression):

  $$\mathbf{B_S = \inf\{d>0 \mid S_B(X_D(d))<t\}}$$

where $X_D(d)$ is the shell around the attractor at distance d. A “fine-tuned” or “razor sharp” basin has small B_S (e.g., d <5% of nominal parameters), meaning tiny changes (e.g., asymmetric weakening) lead to stall/arrest.

- **Basin Entropy (Boundary Unpredictability)**:
  Quantifies fractal or riddled boundaries:

  $$\mathbf{S_{bb} = -\sum p_i \log p_i}$$

  High entropy (>1) indicates unpredictable, “sharp” edges where outcomes snag on small scales.

Diagnostic tools; if models show broad S_B >0.5 or large B_S, *robustness is demonstrated*

Note 3 — Naive Upper Bounds

3.1 Function of Naive Models

Zeroth-order models provide **conservative ceilings** on what gravity alone can achieve. If an event exceeds such ceilings, added mechanisms must be identified and justified.

3.2 Impact-Depth Approximation

Treating the falling section as a projectile into a medium of comparable density yields:

$$\mathbf{s \approx L}$$

where L is projectile length and s is penetration depth.

This upper bound weakens once density increases with depth, reducing expected penetration.

3.3 Inelastic Momentum Exchange

Single-step inelastic collapse:

$$\mathbf{v_{after} = [\, m_1 / (m_1 + m_2)\,] \cdot v_{before}}$$

Arrest occurs when dissipative demand exceeds kinetic energy.

3.4 Breakdown of Naive Models

When naive models cease to be predictive, the system is in a **critical regime** requiring continuum treatment:

- propagating crushing fronts
- dynamic fracture
- compaction waves

The requirement then becomes:

> demonstrate entry into a critical regime and robustness within it.

Note 4 — Energy-Scale Comparisons

4.1 Aircraft Impact

Order of magnitude:

$\mathbf{E_{impact} \sim \mathcal{O}(10^9)\ J}$

Observed:

- limited sway
- survival of global structure
- large reserve still active

4.2 Vertical Drop

Upper-block fall by one story:

$\mathbf{E_{vertical} = mgh \sim \mathcal{O}(10^9)\ J}$

Diagnostic question:

> why a smaller energy increment in the vertical mode is associated with total structural failure when much larger horizontal energies were absorbed?

Amplification mechanisms may resolve this; they must be shown, not assumed.

Tension to be explained, not paradox to be declared

Note 5 — Modeling Scope and Epistemic Geometry

- calibration establishes **plausibility**
- validation requires **out-of-sample predictive success**
- robustness requires **ensemble behavior across variance**

Claims of **inevitability** require the latter two.

Many models to date are calibrated, closed-source, and non-ensemble in character. This is a methodological observation, not an accusation.

Note 6 — Outcome Diversity, Basins, and Reference Classes

Let

$\mathbf{P_{class}(O)}$

be the probability of the observed joint outcome within a reference class.

Low diversity in outcomes demands a synchronizing mechanism. Redundancy typically increases diversity; if it suppresses it, the mechanism must be specified.

The rarity claim is conditional on reference-class characterization; the mechanism question remains central.

Note 7 — Evidentiary Gaps

Gaps include:

- incomplete preservation of physical material
- limited testing regimes
- opacity of simulation inputs
- lack of ensemble statistics
- calibration and validation conflated

These affect not conclusions but **confidence bounds**.

Note 8 — Positive Research Program (Summary)

The following are concrete, falsifiable directions:

- open-source structural simulations
- ensemble runs under parameter variance
- publication of arrest statistics
- scaled physical analog testing
- full sensitivity analyses
- explicit basin-of-attraction mapping

Any result that demonstrates **robust recurrence** of the observed joint outcome under variance would directly weaken replication-difficulty claims.

Final Note

The appendix is not advocacy. It is method. It keeps a clean distinction between:

- what is measured
- what is assumed
- what is derived
- what remains to be shown

That distinction is the central object of this document.

Overview

Claim	Basis Cited	What Was Demonstrated	What Was Not Demonstrated
Progressive collapse was inevitable once initiation began	Bažant (2002–2017); NIST NCSTAR 1 language of “doomed,” “global collapse ensued” BAZANT-405, NCSTAR-1, BAZANT-466	Calibrated models showing plausibility for selected parameter sets	Ensemble robustness, basin size, arrest frequency under variance
Symmetry of descent was natural	Tube/core system + gravity; visual observation BAZANT-405	Post-hoc narrative coherence	Mechanism for suppression of asymmetry, tilt, and partial collapse
Near–free-fall descent compatible with gravity-driven collapse	Video measurements; “essentially in free fall” statements BAZANT-405, NCSTAR-1, NIST-FAQ	Kinematic description	Reconciliation with energy dissipation and reserve capacity under realistic resistance
Fire + impact exhausted reserve capacity	NIST fire simulations and structural analysis NCSTAR-1	Initiation plausibility	Systematic testing of alternative damage/insulation scenarios; partial-failure regimes
Modeling captures progression mechanics adequately	Closed-source FE models; idealized 1-D crushing models BAZANT-405, NCSTAR-1	Case-calibrated trajectories	Independent reproduction, open inputs, sensitivity mapping, out-of-sample validation
Evidence does not support demolition hypotheses	NIST FAQ statements NCSTAR-1, NIST-FAQ	Lack of specific positive findings	Comprehensive residue testing; alternative-hypothesis modeling at equal effort

Chronology of Closure

(The Refusal to Pretend to Know: Pt. III)

Preface: Purpose and Limits

This document examines how explanations of the collapse of the World Trade Center Twin Towers developed, changed, and were socially stabilized over time. Rather than seeking to prove what happened, it asks a more foundational question:

> **How did explanatory closure develop—through what balance of methodological demonstration, practical constraint, and professional convergence?**

The focus is chronological and procedural. We track:

- shifts in technical explanation
- expansion and contraction of uncertainty claims
- treatment of disagreement within scientific and professional communities
- separation between what was modeled and what was asserted
- how public rhetoric converged faster than technical understanding

The limits of this document are explicit:

- It does not attempt event reconstruction.
- It does not adjudicate between causal hypotheses.
- It does not conduct new forensic analysis.
- It does not claim proof of intent, error, or misconduct.

What it does evaluate is **process**:

- whether competing hypotheses were tested symmetrically
- whether evidentiary standards were applied consistently
- whether closure followed demonstration or preceded it
- whether dissent was addressed methodologically or socially

The inquiry matters because closure is never merely academic. When a question as basic as structural collapse behavior is declared settled without transparent resolution of its open problems, the cost is not only technical. The cost is **erosion of public trust in scientific method itself.**

Accordingly, this document should be read alongside *Epistemic Limits and Claims of Inevitability* and the *A Dialectic Inventory On Collapse Mechanics*. Together, they do not argue for an alternative narrative; they argue for something simpler and more demanding:

> that closure in science must arise from method, not decree.

Chapter 1 — Chronology of Explanatory Claims

This section summarizes the evolution of explanatory claims regarding the collapse of the World Trade Center Twin Towers. It focuses on how interpretations were offered, revised, and consolidated over time. The emphasis is descriptive rather than evaluative.

1. Pre-Event Professional Expectations

Before September 11, 2001, professional expectations within structural engineering generally treated large high-rise steel structures as robust against global failure from localized damage.

- Statements following the 1993 bombing described the towers as capable of absorbing aircraft impact loads without global collapse.
- Design engineers noted large safety margins, extensive redundancy, and the high capacity of the framed-tube system.
- In early 2001, interviews characterized an aircraft strike as causing localized damage analogous to perforation of a mesh, without expectation of total failure.

These pre-event expectations formed the baseline from which later surprise was measured.

2. Immediate Characterizations on September 11

During and shortly after the collapses, rapid explanations were offered in real time. These included:

- assertions that intense fires caused progressive structural weakening
- suggestions of “pancake-type” collapse mechanisms
- references to prior impact damage as an initiating factor

These early statements were provisional, made in conditions of uncertainty and without access to detailed structural information. They nonetheless shaped initial public framing.

3. First Days: Competing Hypotheses

In the week following the event, multiple explanatory narratives circulated simultaneously:

- **steel melting due to jet-fuel fires**
- **truss-sagging leading to inward bowing of perimeter columns**
- **progressive floor collapse sequences**
- **inevitability claims based on gravitational progression models**

At this stage, explanations differed not only in mechanism but in emphasis: some focused on temperature thresholds, some on redistribution of loads, and others on dynamic progression after initiation. No single narrative dominated.

4. Institutional Investigations

The institutional investigation period formalized the inquiry process.

- Initial FEMA findings summarized observable damage patterns and explored multiple possible mechanisms.
- NIST later initiated a multi-year investigation emphasizing aircraft impact, fire progression, structural response, and collapse initiation.
- The stated scope explicitly prioritized the sequence up to initiation; post-initiation propagation was generally treated as inevitable once global instability began.

The gradual movement from open hypotheses to a dominant explanatory narrative occurred over this phase.

5. Post-Investigation Consolidation

Following release of the final reports:

- public communications increasingly presented “impact + fire + gravity” as a settled explanation
- much earlier terminology (e.g., steel melting, pancake collapse) was deemphasized or abandoned
- later analytical papers framed further debate as unnecessary or superfluous

Over time, the multiplicity of early hypotheses gave way to a single dominant narrative structure. That narrative did not reflect the diversity of initial viewpoints.

Chapter 2 — Narrative Closure and Treatment of Dissent

This section addresses how explanatory claims were socially and institutionally handled, rather than whether those explanations were correct.

1. From Tentative Statements to Certainty Claims

Early statements were conditional, qualified, and framed as provisional interpretations. Over time, the same types of claims came to be presented:

- as settled fact rather than conjecture
- with decreasing reference to uncertainties and contested assumptions
- with reduced acknowledgment of model dependence

The shift was rhetorical rather than methodological: certainty increased even when model complexities and unknowns remained significant.

2. Changing Stories Without Retrospective Accounting

Throughout the chronology, explanations changed in material ways:

- from “steel melting” to “loss of strength without melting”
- from “pancaking floors” to “column failure driven by inward bowing”
- from “possible collapse” to “inevitable collapse after initiation”

These changes occurred without systematic public documentation of which earlier claims were withdrawn, which were retained, and why revisions were made. The record therefore displays evolution without clear epistemic bookkeeping.

3 The Domino Metaphor and Its Limits

Explanations invoking “domino effects,” “house-of-cards failure,” or generic “chain reactions” are often presented as intuitively sufficient.

Yet when confronted with physical demonstrations—such as record-scale domino towers (~10 m), which require extreme uniformity, deliberate triggering, and controlled boundary conditions—these analogies are quietly withdrawn or requalified. The pattern is diagnostic: explanatory rhetoric outran physical justification. What functioned as public reassurance (“it’s simple physics, like dominoes”) was replaced by technical complexity once the analogy failed under scrutiny.

The retreat itself is not dishonest; it is evidence that early closure was premature, and that intuitive simplicity masked unresolved dynamical questions.

4. Consensus Claims and the Appearance of Uniformity

Over time, media and institutional communication increasingly used formulations such as:

- “experts agree that…”
- “it is now understood that…”

even where the technical literature exhibited:

- multiple competing models
- unresolved quantitative disagreements
- continued debate over assumptions and parameter choices

This produced an appearance of consensus that exceeded the documented level of expert agreement on details.

5 Treatment of Skepticism and Methodological Critique

Method-focused critiques — those questioning modeling assumptions, calibration practices, or the scope of investigations — were often reframed as:

- challenges to institutional authority
- endorsement of specific alternative hypotheses
- “conspiracy” positions

Rather than being addressed within normal scientific discourse, many were moved into social or political categories. The net result was reduced space for ordinary methodological scrutiny.

The treatment of competing hypothesis classes has not only shaped conclusions, but also the standards applied to them. Two recurrent reasoning patterns deserve explicit attention.

5.1 Epistemic Drift Through Contrast

In the absence of detailed, publicly testable mechanical demonstrations, an informational vacuum formed. That vacuum was not filled by improved collapse mechanics but by highly speculative alternatives—directed-energy devices, mini-nuclear charges, "exotic" demolitions. These proposals were technically weak, yet they performed an epistemic function: they supplied a contrast class. The obvious implausibility of such alternatives was then used to retro-validate the official account, producing a self-reinforcing loop in which the weakness of the alternatives substituted for the strength of the primary hypothesis. Debate migrated from questions of mechanism, arrest criteria, symmetry, and robustness to questions of whether speculative scenarios were socially or logistically credible. The engineering question remained underdetermined while rhetorical certainty increased. This dynamic constitutes an epicycle of inevitability: apparent closure generated not by new physical evidence but by selectively degrading alternatives.

5.2 A Category Error in Burden-Shifting

A parallel shift occurred in burden-shifting. Mechanical objections—regarding synchronization of failure, comminution, near-axial descent, and the suppression of lateral modes—were increasingly met with sociological answers rather than mechanical ones: too many people would have to be involved; secrecy would be impossible; logistics would be prohibitive.[BAZANT-EPN] This is a category error. In a mechanical problem, the burden is mechanical: quantified forces, constraints, energy dissipation, load paths, and robustness under variability. Redirecting the discussion to plausibility of conspiracy does not resolve questions of structural sufficiency. In its most compressed form this inversion yielded the argument that because enormous quantities of energetic material would be required, this is evidence that none were required. The extremity of an alternative was taken as confirmation of the primary hypothesis without the primary hypothesis being demonstrated. Rhetorical closure was achieved; mechanical closure was not.

5.3 A Case Study in Technical Discourse

The treatment of technical critiques in the progressive collapse literature provides a window into how dissent was framed and handled. This section examines representative exchanges not to adjudicate their technical merits, but to observe **patterns of discourse** that shaped the closure process.

The Critics

Between 2002 and 2013, several credentialed engineers and scientists published technical critiques of the Bažant collapse models:

- **Gregory Szuladziński** — structural engineer; temporal analysis showing momentum-exchange constraints
- **Robert Korol & K.S. Sivakumaran —** structural engineering professors; energy absorption studies
- **Anthony Szamboti —** mechanical engineer; detailed mathematical critiques
- **Crockett Grabbe —** PhD physicist; analysis of motion characteristics

- **Gennady Cherepanov** — Academician, Russian Academy of Sciences; fracture mechanics analysis
- **James Gourley —** civil engineer; methodological questions

These were not anonymous internet commentators. They were published professionals raising specific technical objections in peer-reviewed venues or formal discussion papers.

Pattern 1: Credential Dismissal

Despite professional credentials, critics were frequently characterized as lacking appropriate expertise.

Bažant's responses employed terms such as: - "lay critics" - "mistaken impression" - "erroneous" - "no meaningful calculations"

Example:

Korol and Sivakumaran—both structural engineering professors with publication records in steel structures—raised questions about energy dissipation and arrest conditions.

Their work was not addressed on technical merits in subsequent Bažant papers. Szuladziński's 2012 temporal analysis, showing that momentum exchange alone imposes significant arrest tendency, was similarly unaddressed in later publications.

Observation:

When substantive technical critiques go unaddressed while their authors are dismissed as unqualified, the discourse departs from normal scientific exchange.

Pattern 2: Strawman Characterization

Critics were frequently described as holding positions they did not hold.

Common characterizations:

"Critics claim free fall"
→ Actual claim: Observed acceleration approached free fall; this requires explanation of minimal resistance.

"Critics claim energy conservation is violated"
→ Actual claim: Energy partitioning among dissipation channels was not adequately demonstrated.

"Critics claim steel must melt"
→ Actual claim: Temperatures achieved may not have produced sufficient weakening across required areas.

Example from Bažant & Verdure (2007):

> "Some critics have been under the mistaken impression that collapse cannot occur if…
> the weight mg of the upper part is less than the load capacity F_0 of the floor. This led

> them to postulate various **strange ideas** (such as”fracture wave" and planted explosives)."

The characterization as “strange ideas” frames technical alternatives as beyond consideration while misrepresenting the underlying objection: not that $F_0 > mg$ prevents collapse, but that claims of inevitability require demonstrating robustness across variance, not just showing compatibility under selected parameters.

Observation:

Engaging a weakened version of critique rather than the strongest version is a departure from rigorous discourse norms.

Pattern 3: The Category Error in Response

Technical objections were sometimes met with non-technical deflections.

The structure:

1. Critic raises mechanical question (e.g., arrest conditions, energy budget)
2. Response shifts to logistical or sociological domain
3. Mechanical question remains unaddressed

Example from Bažant & Verdure (2007):

After presenting energy-based inevitability criterion:

> “If Eq. 5 is violated, there is (regardless of F_0) no way to deny the inevitability of progressive collapse driven only by gravity.”

But then:

> “This could also help to clear up misunderstanding (and thus to dispel the myth of planted explosives).”

Followed by discussion of how conventional demolition would require extensive preparation and “many thousands of pounds” of explosives, which would be “difficult to organize.”

The logical problem:

- Mechanical question: Does the model demonstrate robustness across realistic variance?
- Response: Alternative mechanism would be logistically difficult
- **These do not address each other**

Logistical difficulty of alternative A does not validate model B. Each must stand on its own evidence.

Observation:

When mechanical questions receive sociological answers, discourse has shifted from physics to rhetoric.

Pattern 4: Argument from Incredulity

The pattern recurs:

1. Identify what an alternative would require
2. Express that requirement as extreme or implausible
3. Treat this as evidence for preferred explanation

The form:

- "Demolition would require X tons of material"
- "X tons is difficult to place covertly"
- **Therefore progressive collapse is validated**

The fallacy:

This commits **affirming the consequent**:

- If demolition → large quantities needed
- Large quantities difficult → no demolition
- **Therefore gravity-driven collapse is proven**

The conclusion doesn't follow. Difficulty of one mechanism doesn't validate another. Both require independent demonstration.

Observation:

Arguments from incredulity are rhetorical, not evidential. They function to frame alternatives as absurd without addressing the technical question: Does the preferred model demonstrate what it claims?

Pattern 5: Ignoring Substantive Technical Work

The most methodologically concerning pattern: substantive technical critiques simply not addressed in subsequent literature.

Examples:

Szuladziński (2012) published detailed temporal analysis showing:

- Sequential inelastic collisions dissipate ~1/3 of gravitational potential energy
- Even neglecting structural resistance entirely
- Minimum descent times approach 15 seconds under idealized conditions

This work directly challenges claims of near-free-fall descent being compatible with collision-based progression.

Result: Not cited or addressed in later Bažant papers.

Korol et al. (2011) published energy absorption analysis of floor systems.

Result: Minimal engagement in subsequent literature defending inevitability claims.

Observation:

When technical work raising fundamental questions is simply not addressed, closure occurs by omission rather than rebuttal.

What This Pattern Reveals

The discourse surrounding progressive collapse exhibits features inconsistent with normal scientific exchange:

Normal scientific discourse:

- Substantive critique → substantive response
- Technical objection → technical answer
- Disagreement → clarification or evidence
- Strong claims → proportional burden of proof

Observed discourse:

- Substantive critique → credential dismissal
- Technical objection → sociological deflection
- Disagreement → characterization as “strange ideas”
- Strong claims → assertions of self-evidence

This is diagnostic.

When evidence is strong and models robust:

- Critics are engaged directly
- Best version of objection is addressed
- Testing and verification are welcomed
- Uncertainty is acknowledged

When evidence is weaker or models conditional:

- Critics are dismissed via framing
- Weak version of objection is addressed
- Further testing is deemed unnecessary
- Certainty is asserted

The pattern observed here tilts toward the latter.

The Consequence for Closure

By framing technical dissent as:

- Unqualified (“lay critics”)
- Confused (“mistaken impression”)
- Absurd (“strange ideas”)
- Motivated (“conspiracy theories”)

Legitimate methodological questions were moved **outside the bounds of normal scientific discourse**.

This had a direct effect on closure:

1. **Reduced scrutiny** → Models not subjected to severe testing by critical community
2. **Narrowed discourse** → Range of acceptable questions constrained
3. **Social enforcement** → Career/reputational risk for raising certain objections
4. **Premature consensus** → Appearance of agreement achieved through exclusion rather than resolution

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A Note on Intent

This analysis does not attribute motive or question integrity. The patterns documented here can arise from:

- Genuine conviction in one's conclusions
- Frustration with repeated objections
- Time and resource constraints
- Institutional and political pressures
- Normal human cognitive biases

The **cause** matters less than the **effect**:

Technical discourse was shaped in ways that favored closure over continued scrutiny.

Methodological Implications

The handling of technical dissent matters because:

1. Science depends on critical engagement

Progress occurs when:

- Strong claims face strong tests
- Critique is welcomed, not deflected
- Evidence speaks louder than authority

2. Discourse norms enforce quality

When critique is:

- Engaged substantively → models improve
- Dismissed socially → models ossify

3. Premature closure has costs

If the mechanism is not as well understood as claimed:

- Design codes may be inadequate
- Risk assessment may be wrong

- Future events may not be preventable
- Public trust in expertise erodes

The Contrast with Other Investigations

Compare the treatment of dissent here with other major structural failure investigations:

Tacoma Narrows Bridge (1940):

- Initial explanation (resonance) challenged
- Alternative mechanism (aeroelastic flutter) proposed
- Extensive testing validated new understanding
- Dissent drove progress

Hyatt Regency Walkway (1981):

- Multiple explanations explored
- Design flaw identified through systematic investigation
- Professional disagreements resolved through evidence
- No dismissal of credentials

WTC Progressive Collapse:

- Early inevitability claims
- Critical responses dismissed or unaddressed
- Further detailed modeling deemed unnecessary
- Dissent framed as outside legitimate discourse

The difference in pattern is notable.

Conclusion

The treatment of technical dissent in progressive collapse literature exhibits systematic departures from norms of scientific discourse:

- Credential dismissal over substantive engagement
- Strawman characterization over steel-man response
- Sociological deflection over mechanical rebuttal
- Argument from incredulity over evidential demonstration
- Selective non-engagement with substantive critique

These patterns are **diagnostic**, not of the truth of any particular mechanism, but of the **quality of the epistemic process**.

When closure occurs through such mechanisms, it is **social rather than scientific**.

This does not prove:

- The official explanation is wrong
- The critics are right

- Intent to deceive existed

It shows:

- Closure preceded full methodological resolution
- Discourse was shaped by non-technical factors
- Standards were applied asymmetrically

And it raises a question:

If the mechanism were as robust and well-demonstrated as claimed, why would such discourse patterns be necessary?

> These patterns do not resolve the collapse question. They identify places where reasoning has slipped from physics into preference. *The refusal to pretend to know begins by noticing those slips.*

Chapter 3 — Why Epistemic Closure Matters Beyond This Case

1. The Structural Problem of Complexity

Modern life demands judgment on questions that lie beyond individual expertise:

- vaccine safety
- climate dynamics
- financial stability
- AI governance
- structural failure

This is not a failure of education. It is a **structural feature** of knowledge in complex societies. Citizens must rely on **expert consensus**—but only if that consensus is **earned through method**, not declared by authority.

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2. When Closure Precedes Demonstration

The WTC collapse appears straightforward: steel, fire, gravity, video evidence. Yet even here, we observe:

- shifting explanations (steel melting → fireproofing loss → inward bowing)
- calibration presented as validation
- dissent reframed as deviance
- evidentiary gaps treated asymmetrically

If expert communities cannot stabilize around a transparent, reproducible account of **why buildings fall**, what confidence can citizens hold in claims about novel biologics, opaque financial instruments, or self-modifying algorithms?

This is not an anomaly. It is a **pattern of epistemic closure under complexity**: consensus declared before mechanism is demonstrated.

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3. The Democratic Cost of Asymmetric Information

Democracy assumes citizens can reason about the policies that govern them. But when reasoning requires access to contested, inaccessible, or prematurely closed expertise, two paths remain:

1. **Uncritical deference—**trusting authority without means to evaluate its integrity.
2. **Total rejection—**falling into conspiracism or nihilism.

The middle path—**critical trust**—requires experts to:

- document uncertainties honestly,
- preserve discriminating evidence,
- adjudicate disputes **methodologically**, not socially,
- distinguish **what is known** from **what is assumed**.

When these commitments are abandoned, the cost is not technical—it is **civic**: the erosion of collective capacity for reason.

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4. Echo Chambers, Amplified Algorithmically

Large language models do not “think.” They **reflect the epistemology of their training data**. If that data contains:

- rhetorical claims of inevitability unsupported by ensemble modeling,
- dismissals of methodological critique as conspiracy,
- consensus declared before robustness is shown,

then AI systems will **confidently reproduce and amplify those weaknesses—**not as lies, but as settled fact.

This creates **epistemic lock-in**: once a narrative is encoded at scale, dislodging it requires overcoming not just institutional inertia, but **algorithmic reinforcement**. The result is not misinformation, but **overconfidence in unresolved claims**.

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5. A Recurring Pattern, Not an Isolated Failure

The WTC case mirrors others:

- **Medicine**: Hormone therapy, opioids—early dissent dismissed, harm revealed later.
- **Finance**: AAA-rated securities, ignored correlation risk, systemic collapse.

- **Engineering**: Levees, Fukushima, Challenger—models calibrated, not validated; warnings marginalized.

The sequence is consistent:

1. Complex system
2. Model-dependent risk
3. Consensus declared
4. Dissent dismissed
5. Catastrophic failure
6. Post-hoc admission: “We underestimated uncertainty.”

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6. Science vs. Authority

Science is not consensus. It is:

- **transparency** of method,
- **reproducibility** of result,
- **falsifiability** of claim,
- **willingness to be wrong**.

When these are replaced by credential, rhetoric, or social enforcement of agreement, what remains is **authority wearing the costume of science**—and the public increasingly sees through it.

7. Earned Closure, Not Declared Closure

The standard should not be:

> “Experts agree, therefore it’s settled.”

It should be:

> “Here is the method, the assumptions, the uncertainties, the evidence, and how dissent was addressed.”

Earned closure arises from open data, independent reproduction, and symmetric hypothesis testing. **Declared closure** arises from opacity, asymmetry, and dismissal.

One sustains trust. The other destroys it.

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8. The WTC as Bellwether

If expert communities cannot transparently resolve disagreements about **classical mechanics in a globally observed event**, then the crisis is not domain-specific. It is in the **epistemic commons itself**.

When citizens see:

- shifting stories without accounting,

- evidence destroyed rather than preserved,
- critique pathologized rather than engaged,

they reasonably infer: **the goal is not truth, but closure**.

That inference is structurally inevitable when method yields to narrative.

9. The Refusal to Pretend to Know as Civic Practice

The refusal to pretend to know is not skepticism. It is:

- **methodological humility**,
- **epistemic hygiene**,
- **democratic necessity**.

In a world of irreducible complexity, expertise is indispensable—but only if it **earns trust through discipline**, not claims it through consensus.

If we cannot maintain that discipline in a case as concrete as **why buildings fall**, we will fail in cases where evidence is sparser, stakes higher, and errors lethal.

The question is not what happened on 9/11.

It is: **Can expert processes be trusted to follow their own standards when uncertainty is high and pressure is greater?**

The answer determines whether complexity remains navigable—or becomes a trap.

Conclusion

1. Why the Inquiry Remains Justified

Across *Epistemic Limits and Claims of Inevitability*, the *Dialectic Inventory*, and the present document, one conclusion is consistent:

- not that any alternative explanation is proven
- not that any official explanation is disproven
- but that **epistemic closure is unearned**

The replicability problem, the model-dependence problem, the evidentiary-preservation problem, and the rhetoric-of-consensus problem all point to the same modest conclusion:

> **further open inquiry is still warranted**.

This is not a political claim. It is a methodological one.

The appropriate end state is:

- open data where possible
- explicit uncertainty where required
- symmetric treatment of hypotheses

- ensemble-based evaluation of robustness
- preservation of material and computational evidence

Science does not protect public trust by insisting it is already finished. It protects public trust by **showing how it corrects itself.**

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2. Forward Linkage

Together, *Epicycles of Inevitability* now form a coherent architecture:

1. **Epistemic Limits and Claims of Inevitability** — account of internal tensions and incoherencies in popular explanations
2. **A Dialectic Inventory** — physics and modeling difficulty of the observed phenomena
3. **Chronology of Closure —** social trajectory of explanation and its consequences

The task that remains is straightforward and non-ideological:

- reopen methodological questions without presuming answers
- evaluate robustness across variance rather than single tuned runs
- treat disagreement as instrument, not as stigma

Only then does the inquiry satisfy its own standard:

> physics first, method second, epistemology last — and closure never by decree.

Timeline: Evolution of the scientific consensus on the collapse of the WTC Twin Towers

Before it happened

could still withstand

1964 Engineering News-Record http://911research.wtc7.net/mirrors/guardian2/wtc/eng-news-record.htm

> "The World Trade Center towers would have an inherent capacity to resist unforeseen calamities" […]
> "live loads on [the perimeter columns] can be increased more than 2,000% before failure occurs" […]
> One "could cut away all the first story columns on one side of the building, and partway from the corners to the perpendicular sides, and the building could still withstand design live loads and a 100 mph wind from any direction."[…]

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could not cause collapse

John Skilling: 1964 (cited in: NIST NCSTAR 1-2, Appendix A)
http://www.nist.gov/el/disasterstudies/wtc/wtc_finalreports.cfm

> The buildings have been investigated and found to be safe in an assumed collision with a large jet airliner (Boeing 707-DC8) traveling at 600 miles per hour. Analysis indicates that such collision **would result in only local damage and could not cause collapse**.
> *(pp. 306 ff)*

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would not be endangered

Thomas W. Ennis: "Critics Impugned on Trade Center; Towers Called Safe"; New York Times February 15, 1964 http://wayback.archive.org/web/20131227133223/http://www.nytimes.com/1964/02/15/nyregion/15WTC.html

> Richard Roth of the architectural firm of Emery Roth & Sons issued the statement defending the safety of the twin towers, which the firm, in association with Minoru Yamasaki, designed for the center.
> Mr. Roth said that a structural analysis by the firm of Worthington, Skilling, Helle & Jackson had found that if a tower were hit by an airliner at 600 miles an hour, the

> damage to the tower would be only local and its occupants outside the immediate area of impact would not be endangered.

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essentially a steel beam

Henry Hold and Company, LLC: “City in the Sky”; Times Books 2003
http://911research.wtc7.net/wtc/analysis/design.html

In 1965, real estate baron Lawrence Wien charged that the design of the Twins is structurally unsound. Richard Roth fired back with a 3-page telegram:

> THE STRUCTURAL ANALYSIS CARRIED OUT BY THE FIRM OF WORTHINGTON, SKILLING, HELLE & JACKSON IS THE MOST COMPLETE AND DETAILED OF ANY EVER MADE FOR ANY BUILDING STRUCTURE. THE PRELIMINARY CALCULATIONS ALONE COVER 1,200 PAGES AND INVOLVE OVER 100 DETAILED DRAWINGS. …
> BECAUSE OF ITS CONFIGURATION, WHICH IS ESSENTIALLY THAT OF A STEEL BEAM 209’ DEEP, THE TOWERS ARE ACTUALLY FAR LESS DARING STRUCTURALLY THAN A CONVENTIONAL BUILDING SUCH AS THE EMPIRE STATE BUILDING WHERE THE SPINE OR BRACED AREA OF THE BUILDING IS FAR SMALLER IN RELATION TO ITS HEIGHT. …
> THE BUILDING AS DESIGNED IS SIXTEEN TIMES STIFFER THAN A CONVENTIONAL STRUCTURE. THE DESIGN CONCEPT IS SO SOUND THAT THE STRUCTURAL ENGINEER HAS BEEN ABLE TO BE ULTRA-CONSERVATIVE IN HIS DESIGN WITHOUT ADVERSELY AFFECTING THE ECONOMICS OF THE STRUCTURE. *(pp. 134 ff)*

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some damage

1988 :: *Structural engineer* Charlie Thornton *explains that a fully loaded 747 — a three hundred ton element — crashing into a building that has been designed to carry thirteen thousand tons would probably not do anything to the major building. It could affect localized structural elements, knock out a column, and there could be some damage, but as far as a plane knocking a building over of that type, that would not happen.* [YT]

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the building structure would still be there

Eric Nalder: “Twin Towers Engineered To Withstand Jet Collision”; The Seattle Times February 27 1993 http://community.seattletimes.nwsource.com/archive/?date=19930227&slug=1687698

> Skilling, based in Seattle, is among the world’s top structural engineers. He is responsible for much of Seattle’s downtown skyline and for several of the world’s tallest structures, including the Trade Center.
> Concerned because of a case where an airplane hit the Empire State Building, Skilling’s people did an analysis that showed the towers would withstand the impact of a Boeing

707.
"Our analysis indicated the biggest problem would be the fact that all the fuel (from the airplane) would dump into the building. There would be a horrendous fire. A lot of people would be killed," he said. "The building structure would still be there."
Skilling - a recognized expert in tall buildings - doesn't think a single 200-pound car bomb would topple or do major structural damage to a Trade Center tower. The supporting columns are closely spaced and even if several were disabled, the others would carry the load.
"However," he added, "I'm not saying that properly applied explosives - shaped explosives - of that magnitude could not do a tremendous amount of damage."

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just a pencil puncturing a steel netting

January 25th, 2001 :: *The towers' construction manager,* Frank deMartini, *explains the building was designed to have a fully loaded 707 crash into it. He believes the building could probably sustain multiple impacts because the structure is like the mosquito netting on a screen door — an intense grid, and the jet plane is just a pencil puncturing that screen netting, really doing nothing.* [YT]

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noone thought

September 11th, 2001, 9:05 a.m. :: In the lobby of the north WTC tower, just after the South Tower is hit, Fire Commissioner Thomas Von Essen speaks briefly to Fire Chief *Ray Downey*. According to Von Essen, Downey — who is a highly respected expert on building collapses — says to him, "You know, these buildings can collapse." Von Essen later recalls, "He just said it in passing, not that these buildings will collapse in 40 minutes and we have to get everybody out of here, or not that they'll collapse by tomorrow, or not that they necessarily will collapse at all. Just that they can collapse." But other firefighters do not appear to have shared this concern. According to the National Institute of Standards and Technology (NIST), the Fire Department command officers who are planning for operations inside the Twin Towers expect that there will "be localized collapse conditions on the damaged fire floors," but do "not expect that there [will] be any massive collapse conditions or complete building collapse." At the end of its three-year investigation of the WTC collapses, NIST will report, "No one interviewed indicated that they thought that the buildings would completely collapse." [National Institute of Standards and Technology, 9/2005, pp. 72 and 75-76] Deputy Fire Commissioner Lynn Tierney will meet up with Downey and others —including Von Essen—slightly later, on the south lawn of the WTC complex, where a new command center is set up. At that time, according to Tierney, Downey will only be concerned that the 360-foot antenna atop the North Tower will fall, and "No one ever thought the towers were going to come down." [Pittsburgh Tribune-Review, 9/11/2006] However, shortly before the first tower comes down, EMT Richard Zarrillo will be asked to relay a message to some senior firefighters that the mayor's Office of Emergency Management "says the buildings are going to collapse". And later in the day, Mayor Giuliani will recount that around the same time, he had been told "that the World Trade Center was going to collapse". The 9/11 Commission will state, "The best estimate of one senior [fire] chief, provided to the chief of the department sometime between 9:25 and 9:45, was that there might be a danger of collapse [of the South Tower] in a few hours, and therefore units probably should not ascend above floors in the sixties." The Commission does not state, however, whether this fire chief was referring to a total building collapse or just a localized collapse. [historycommons]

As it happened

oh my god

September 11th, 2001, during and seconds after South Tower collapse :: *Reporters are at a loss of words, speak of a "huge explosion", compare the collapse to a controlled demolition, speculate a large part fell off or that the towers were reduced to a pile of rubble.* [YT]

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a witness

September 11th, 2001, minutes after North Tower collapse :: *Mark "Harley Guy" Walsh* witnessed both collapses, which happened mainly due to structural failure; because the fires were just too intense. [YT]

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we believe

September 11th, 2:40pm :: Asked at a press conference about the cause of the explosions that brought the two buildings down, mayor *Rudy Giuliani* replies "We believe that it was caused by the after effects of the planes hitting the buildings." [YT, transcript] :: For the collection of oral histories by journalists who covered the attacks "Running Toward Danger - Stories Behind the Breaking News of 9/11" (July 16th, 2002), *Beth Fertig*, WNYC reporter, will remember: "I spent the rest of the afternoon at the mayor's command center. The reporters were trying to figure out what happened. We were thinking that bombs had brought the buildings down. The mayor [Giuliani] talked to us and said he had no evidence of bombs." (p. 203) [Running Towards Danger]

First reactions

lucky design choice

September 12th, 2001 :: *New Scientist* says a lucky design choice saved lives. Most buildings would have come down immediately, but the towers remained upright for nearly an hour. Eventually raging fires melted the supporting steel struts, but the time delay allowed hundreds of people to escape. It's a good thing they didn't fall over. [New Scientist]

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shredding downward

September 12th, 2001 :: *Arizona Wildcat* reports that according to experts, although the impact of the jetliners was strong, it was the heat from the explosion that most likely caused the buildings to collapse and cites *Richard Ebeltoft*, a structural engineer and University of Arizona architecture lecturer, who speculates that flames fueled by thousands of gallons of aviation fuel melted the buildings steel supports. Once the top of the building lost balance, the floors appear to have begun shredding downward. [Arizone Wildcat]

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designed to do that architecturally

September 12th, 2001 :: *CBS Local News NY* cite *PANY* sources explaining that the building actually collapsed the way it did – as if it was imploding unto itself – because it was designed to do that architecturally in order to minimize collateral damage. Had it gone into a million different directions, it could have done even more damage. The towers were designed to fall that way if they were ever met with tragedy. [YT]

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careful calculation or evil luck

September 12th, 2001 :: The *Los Angeles Times* article "2 Planes Hit Twin Towers at Exactly the Worst Spot" quotes experts *Nabih Youssef* (structural engineer heading the Tall Building Council in Los Angeles, expert on design and strength of skyscrapers), *Greg Fenves* (professor of civil engineering at UC Berkeley), *Ron Hamburger* (chief structural engineer for ABS Consulting in Oakland; past president of the Structural Engineers Assn. of California), *Scott Gustafson* (owner of Demtech Inc. of Blue Springs, Mo., one of the world's leading demolition experts), *Hank Koffman*, *Ron Klemencic* (president of Skilling Ward Magnusson Barkshire (the Seattle firm that engineered the World Trade Center)), *James C. Anderson* (professor of civil engineering at USC), *Jon Magnusson* (chairman and chief executive of the Skilling firm) and *John Hooper* (structural engineer with the Skilling Ward Magnusson firm): the terrorists hit the buildings at their weakest spot to cause their disastrous collapse like hitting someone at the back of the knee, knowing what they were doing, as they showed some knowledge of physics in the attempt to make the hits as low as possible. Demolition of a building the size of the Twins would require hundreds of charges around the building, and it's inconceivable anyone would be able to place that many charges, even with years of planning. *Hamburger* is "personally very surprised to see the entire building collapse". The impact and heat generated burning jet fuel would suffice to destroy the buildings instead. One thing led to another, and it just kept snowballing – the terrorists were evil geniuses: one floor falls on top of the floor below it, and with one floor falling on top of another there's no way to stop it. The south tower collapsed first, even though hit by the second plane, because the fireball was larger and because the plane hit the corner of the building, rather than the center, where there is more structural support. However, the tubular design is a famous, very well-designed structural system. Steel buildings in general are known for their strength – even less well-designed steel buildings survived the 1906 earthquake in San Francisco and the 1933 Long Beach quake. [LA Times]

so predictable

September 13th, 2001 :: *BBC* depict the towers' core as a single steel reinforced concrete column, explain that the tower's ultimate collapse was inevitable because once the steel frame on one floor had melted, it collapsed downwards, inflicting massive forces on the already-weakened floor below. Structural engineer *Chris Wise* says "it was the fire that killed the buildings. There's nothing on earth that could survive those temperatures with that amount of fuel burning. The columns would have melted, the floors would have melted and eventually they would have collapsed one on top of each other" and "the top was acting like a huge piledriver" :: The buildings' construction manager *Hyman Brown* says "Steel melts, and 24,000 gallons of aviation fluid melted the steel. Nothing is designed or will be designed to withstand that fire" and John Knapton, professor in structural engineering at Newcastle University, UK, knew the building would fall within two hours: "The eventual collapse of the twin towers was so predictable that the order should have been given to withdraw emergency services within an hour." [BBC News]

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doomed

September 13th, 2001 :: *Professor Z.P. Bažant* circulates first drafts of a simple analysis of the likely scenario. Assuming a collapse time of ~9s, with the stated aim to prove that the towers must have collapsed and do so in the way seen, approximates that under most optimistic assumptions, the towers were doomed because the percentage of the kinetic energy dissipated plastically is of the order of 1%. The reason is the dynamic consequence of the prolonged heating of the steel columns to very high temperature. The heating caused creep buckling of the columns of the framed tube along the perimeter of the structure, which transmits the vertical load to the ground. Since the plastically dissipated energy W[p] is, optimistically, of the order of 0.5 GN m, and the total release of gravitational potential energy is W[g] = mg 2h = 4.2 GN m, even under the most optimistic assumptions by far, the plastic deformation can dissipate only a small part of the kinetic energy acquired by the upper part of building. :: The paper, co-authored by *Yong Zhou*, is published in the *Journal of Engineering Mechanics* January 1st, 2002. [Source]

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limit state conditions

September 17th, 2001 :: *G. Charles Clifton*, HERA Structural Engineer, for *tenlinks.com* explains that the gravity and lateral load-resisting systems were designed to deliver the strength and stiffness required from a 110 story building with minimum dead load. This was achieved very well, with a steelwork weight of only 44.5 kg/m² floor area. The very light and open structure, superbly engineered to meet the design serviceability and ultimate limit state conditions on a building of this height and size, probably made the buildings more vulnerable to collapse from the aircraft impact than would have been the case for a more inefficient and heavier structural system. In his opinion the fires had a less important role to play in the collapse of both towers than the damage from the initial impact. It took both to cause the collapse, however the fire was in no way severe enough to have caused the collapse on its own. [TenLinks.com]

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no clue

September 17th, 2001 :: According to the enr.com cover story " Massive Assault Doomed Towers - Terrorist Attacks Brings Down World Trade Center" by *Nadine M. Post* with *Sherie Winston*, *Jon D. Magnusson*, chairman-CEO of Skilling Ward Magnusson Barkshire Inc., Seattle, one of the successor firms of Skilling Ward Christiansen Robertson, structural engineer for the original World Trade Center, says: “From what I observed on TV, it appeared that the floor diaphragm, necessary to brace the exterior columns, had lost connection to the exterior wall.” When the stability was lost, the exterior columns buckled outward, allowing the floors above to drop down onto floors below, overloading and failing each one as it went down. :: *Mark Loizeaux*, president of Controlled Demolition Inc., says: the 1,362-ft-tall south tower, which was hit at about the 60th floor, failed much as one would fell a tree. That is what was expected. But the 1,368-ft-tall north tower, similarly hit but at about the 90th floor, “telescoped”. It failed vertically, rather than falling over. Regarding the cause of the telescoping, he says “I don’t have a clue.” [ENR 1, ENR 2]

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assured for years

September 20th, 2001 The *Los Angeles Times* article “A Weapon Unfathomed: Jet Fuel” by *John J. Goldman*, *David Zucchino* and *Matea Gold* remarks that the sight of those towers crumbling so quickly was never anticipated by generations of trade center officials and Fire Department commanders, who were assured for years by engineers that the towers could stand up to a crashing Boeing 707, quoting Fire Lt. *Andrew Graf* as saying “Our guys stayed in there so long because they didn’t think the building would come down.” :: Project engineer for the Twin Towers *Hyman Brown* says “we thought of the structural impact of a plane hitting, but not the burning fuel.” [LA Times]

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strong enough

October 2001 :: *Tufts Journal* quotes *Masoud Sanayeis*, professor of civil and environmental engineering, saying the buildings were strong enough to survive the impact of the airplanes but collapsed as a result of the ensuing fire. The buildings were designed using a tube-in-tube structural arrangement, creating a system that is very stiff and strong and able to resist lateral loads such as wind or an earthquake. The towers survived the initial impact. But the large amount of jet fuel delivered to the towers followed by explosions and subsequent fire weakened the floor systems and the columns. He suspects the fire created temperatures higher than what is normally experienced in office building fires caused by burning furniture or rugs or paper. The building still had to carry the massive loads of higher floors above the plane crash location. The structural columns could no longer carry the gravity loads of the floors above the fire. In addition, the heat could have weakened the floor systems above, as well as the floor-to-column connections. This combination caused the top-down collapse, producing a domino effect. The exterior columns that formed the outside tube of the World Trade Center buildings guided the self-contained collapse within these buildings. It looked like a designed and time-delayed implosion that took only a few seconds to bring each tower down. If there had been no fire, potentially the buildings could have survived. [Tufts Journal]

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performed admirably

November 7th, 2001 :: *Scientific American* reports on a panel of Boston area-based civil and structural engineers who convened to discuss the fate of the superskyscrapers on the campus of the Massachusetts Institute of Technology. *Robert McNamara* says that the World Trade Center was probably one of the more resistant tall building structures. The buildings displayed a tremendous capacity to stand there despite the damage to a major portion of the gravity system. The lateral truss systems redistributed the load when other critical members were lost. It's a testament to the system that they lasted so long. According to him, the planes hit at just the right place. The truck bomb attack showed that the explosion at the bottom had little effect and that it's much easier to collapse a building from the top than the bottom. If they had hit the very top of the building, the fire damage wouldn't have had such a catastrophic effect. At the bottom, the columns are much heavier and stronger and so they would have taken a much larger load. :: *Eduardo Kausel*, M.I.T. professor of civil and environmental engineering, says the World Trade Center was never designed for the massive explosions nor the intense jet fuel fires that came next — a key design omission. Kausel says the towers performed admirably; they stood long enough for the majority of the people to be successfully evacuated. He approximates that about 30 percent of the collapse energy was expended rupturing the materials of the building, while the rest was converted into the kinetic energy of the falling mass, concluding that the the largest share of the kinetic energy was converted to heat, material rupture and deformation of the ground below. He goes on to explain that the intense heat softened or melted the structural elements—floor trusses and columns—so that they became like chewing gum, and that was enough to trigger the collapse. The floor trusses are likely to have been the first to sag and fail. As soon as the upper floors became unsupported, debris from the failed floor systems rained down onto the floors below, which eventually gave way, starting an unstoppable sequence. The dynamic forces are so large that the downward motion becomes unstoppable. He determines that the fall of the upper building portion down onto a single floor must have caused dynamic forces exceeding the buildings' design loads by at least an order of magnitude and performed computer simulations indicating the building material fell almost unrestricted at nearly the speed of free-falling objects. According to his hypothesis, the towers' resistive systems played no role. Otherwise the elapsed time of the fall would have been extended. Asked why the top did not tip over, he answers: "A tree is solid, whereas building is mostly air or empty space; only about 10 percent is solid material. Since there is no solid stump underneath to force it to the side, the building cannot tip over. It could only collapse upon itself." :: Unnamed, but well-informed correspondents are quoted with the suggestion that the aviation fuel fires burned sufficiently hot to melt and ignite the airliners' aluminum airframe structures. Aluminum, a pyrophoric metal, could have added to the conflagrations. Hot molten aluminum could have seeped down into the floor systems, doing significant damage. [Scientific American]

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avalanche theory

November 11th, 2001 :: *James Glanz* in “A NATION CHALLENGED: THE BUILDINGS; In Collapsing Towers, a Cascade of Failures” for the *NY Times* also cites *Jon Magnusson* as saying that the most likely series of events would involve the floor supports. If a member like the connections around the outside of the floors failed in a fire, that could mean the whole floor could go. :: The exterior columns could then have buckled under the tremendous weight above them, says *William F. Baker*, in charge of structural engineering at the architectural firm Skidmore, Owings & Merrill. :: *Eduardo Kausel* believes that the avalanche theory is correct. Once the columns on those few floors buckled, the rest of the columns had no chance of stopping the collapse: “they simply popped out of the way of the avalanche like matchsticks”. :: *Yogesh Jaluria*, professor of mechanical and aerospace engineering at Rutgers, is cited saying that the jet fuel immediately began burning at much higher temperatures than those of ordinary office fires, and that the temperature would have ’jumped exponentially" at the center of the impact zone. :: *Matthys Levy* doesn’t disagree that the floors must have collapsed at some point, but doesn’t think that’s enough to cause the building to go down. [NY Times]

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within a nanosecond

November 19th, 2001 :: *John Seabrook* interviews *Jon Magnusson*, who says that ninety-nine per cent of all buildings would collapse immediately when hit by a 767 :: Among the dozens experts in the construction of tall buildings Seabrook has spoken to, only one said that he **knew immediately**, upon learning, from TV, of the planes’ hitting the buildings, that **the towers were going to fall**. This was *Mark Loizeaux*, the president of Controlled Demolition Incorporated that specializes in reducing tall buildings to manageable pieces of rubble. “Within a nanosecond,” he told. “I said, ‘It’s coming down. And the second tower will fall first, because it was hit lower down.’” [New Yorker]

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hasn’t fallen yet

December 6th, 2001 :: *Blair Kamin*, architecture critic, for *The Chicago Tribune* interviews senior vice president at Construction Technology Laboratories in north suburban Skokie, *W. Gene Corley*: “I said: ‘At least it hasn’t fallen yet. But if they don’t get the fire out, it will.’” “The aircraft hits wounded the buildings, but they could have recovered if it weren’t for the fire” :: The article also states that no one has authoritatively explained why One World Trade Center remained standing for 1 hour and 40 minutes while Two World Trade Center crashed to the ground just 56 minutes after impact. Another mystery is why smaller, nearby structures remained standing even though fire and steel from the twin towers rained down on them and even ripped huge chunks out of their facades. :: It also names three possible collapse scenarios: exterior column, interior column or floor truss failure. [Chicago Tribune]

The next years

would have collapsed without fire

January 9th, 2002 :: *Richard Gewain*, a senior engineer at Maryland-based Hughes Associates and a member of the federally designated panel of engineers probing the collapses, says the major insult was the plane knocking out the columns, and destroying the connections to the floors. Conceivably, the building would have collapsed without the fire. The impact was so tremendous that each building's fireproofing was rendered irrelevant. [Source, Mirror]

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as a result, the building collapsed

March 6th, 2002 :: Funded by the *Federal Emergency Management Agency*, Dr. *Abolhassan Astaneh-Asl*, professor of civil and environmental engineering at the University of California, Berkeley, under the Directorate of Engineering of the National Science Foundation (NSF), is one of five expert witnesses invited to testify before the Committee on Science of the U.S. House of Representatives at the hearing "Learning from 9/11 – Understanding the Collapse of the World Trade Center". Dr. Astaneh-Asl's presentation includes a movie of a simulated crash of a passenger aircraft onto a generic steel structure created with MSC.Dytran and MSC.Marc Nonlinear Software. While the impact of the crash substantially weakened the structure, "the remaining steel beams and columns melted because of the extreme temperatures. Also buckling in the trusses was possible, especially after the damaged crossbeams were unable to provide lateral support. As a result, the load could no longer be distributed and the building collapsed." [Source]

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one after another

April 30th, 2002 :: *NOVA (PBS)*, for "Why the Towers Fell", create an animation showing how the columns were a loose bundle of straws, gaining all their stiffness solely from the floor slabs, and then of a pancake collapse that leaves the core standing up. *Matthys Levy* (author of "Why buildings fall down") explains: "As the steel began to soften and melt, the interior core columns began to give. Then you had this sequential failure that took place where it all pancaked — one after the other." [YT, transcript (PBS)]

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proper parameters

June 2002 :: *Lu Xinzheng* and *Jiang Jianjing* present a LS-DYNA FEA "Simulation for the Collapse of WTC after Aeroplane Impact". They say the simulation results are very close to the real situation, which means that such type of special damage process can be recurred on the computer with proper parameters and numerical model. The results show that the direct reason for the collapse is the softening of steel under fire and the chain reaction damage of floors under the impact load of upper floors. If the fire resistance and the ductility of the structure are improved, the collapse may be avoided. As the fracture of steel is considered in this analysis, the failure plastic deformation is discussed as parameters, whose value is set as 0.5%, 1% and 5% respectively. If the fracture plastic strain of steel structure is 0.5%, the chain collapse will take place entirely. However, if the fracture strain is improved to 1%, the impact energy of upper floors will be absorbed by the lower structures and the chain collapse will be stopped at about 100m under the airplane impact zone. When the fracture strain is improved to 5%, only part of the structure near the airplane impacting zone will be damaged, and no chain collapse will take place. Hence, if the structure has enough ductility to absorb the energy of upper floors' collapse, the chain damage will be controlled. Even though the influence of heap load is considered, the towers still have much larger chance to escape from the entire collapse. [Source]

FEMA: rapidly converted energy

September 1st, 2002 :: *FEMA* publishes the "World Trade Center Building Performance Study" and finds that the structure was able to successfully redistribute the building weight after the plane impacts to the remaining elements and to maintain a stable condition, and that the structure may have been able to remain standing in this weakened condition for an indefinite period. However, fires heated floor framing and slabs, causing expansion, which developed additional large stresses in some members. As the temperature of column steel increased, the yield strength and modulus of elasticity degraded and the critical buckling strength of the columns decreased and initiated buckling, a significant effect in the failure of the interior core columns. Once collapse initiated, much of the potential energy was rapidly converted into kinetic energy. As the large mass of the collapsing floors above accelerated and impacted on the floors below, it caused an immediate progressive series of floor failures, punching each in turn onto the floor below, accelerating as the sequence progressed in a pancake-type collapse of successive floors. [FEMA]

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no biggie

September 11th, 2002 :: For *Naples Daily News*, *Ralf Kircher* interviews *Bernard Panto*, who worked in various positions as an engineer on the World Trade Center construction project. He had heard that a plane had hit the World Trade Center, but had thought to himself that it was nothing to worry about. "No biggie," he said to himself. "Can't knock that building down." [Naples Daily News]

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bolts popped and fell apart

October 28th, 2002 :: *Jaime Holguin* for *CBS* reports that the single-bolt connections in the framework of the World Trade Center popped and fell apart, causing the floors to collapse on top of each other. According to an analysis conducted by a team of researchers from the *Massachusetts Institute of Technology*, the bolts did not properly secure the towers' steel floor trusses. The bolts were pulled toward the center of the buildings while the floor trusses sagged. [CBS News]

February 5th, 2003 :: According to an analysis by *Jim Quintiere* of the University of Maryland, College Park, had the fire-proofing insulation on the towers' steel structures been thicker, the towers would have survived longer and might even have remained standing after they were hit by the hijacked planes. (New Scientist)

vulnerable point

November 24th, 2003 :: *The Sunday Times*, in an article called "Kamikaze attackers may have known twin sisters' weak spot", cite a top British structural engineer, *Gordon Masterson*, who says the airplanes crashed into the Twins at their most vulnerable spot, which suggests the suicide attackers may have known where to strike. Structural damage from this impact, and the searing heat of blazing aviation fuel, then combined to bring down the top 20 floors. The accumulating weight caused both buildings to collapse, floor by floor, faster and faster. If they had struck right at the top of the tower that would have had a greater effect on the foundations, but the fire would have been more contained. However, they struck in both cases at an extremely vulnerable point. :: *Marc Mimram* says very tall buildings are prey to a phenomenon called moment tensor inversion - a shock from a seismic wave or impact that ripples through the building but has a whiplash, leveraged effect on its higher floors. [Sunday Times]

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collapse could be avoided

December 1st, 2003 :: *Abdolhassan Astaneh-Asl* in "World Trade Center Collapse, Field Investigations and Analyses" opines that the highly redundant exterior tube of the World Trade Center with many closely spaced columns was able to tolerate the loss of many columns and support the gravity while almost all occupants who could use a stairway escaped to safety. The collapse of the towers was most likely due to the intense fire initiated by the jet fuel of the planes and continued due to burning of the building contents. It is also the opinion of the author that had there been better fireproofing installed to delay the steel structure, specially the light weight truss joists and exterior columns from reaching high temperature until the content of the buildings burned out, probably the collapse could be avoided and the victims above the impact area rescued. [Source]

9/11 Report: hollow steel shaft

July 22nd, 2004 :: The *National Commission on Terrorist Attacks Upon the United States*, an independent, bipartisan commission created by congressional legislation and the signature of President George W. Bush, issue their final report which states that the interior core of the buildings was a hollow steel shaft. [Source]

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only way they could fail

July 23rd, 2004 :: *Liz Else* interviews *Mark Loiseaux* for *The New Scientist* article "Baltimore Blasters", who says when he saw that it was an airliner that hit, he remembered the long clear span configuration from the central core to the outer skin of the World Trade Center from a school report he did, and *CDI* had just taken down two 40-storey structures in New York. “I still had some cellphone numbers so when the second plane hit I said: ‘Start calling all the cellphones, tell them that the building is going to come down.’ […] And I sat there watching, I picked up the phone and I called a couple of people on the National Research Council Committee involved in assessing the impact of explosives. They said: ‘What do you think this is, that they’re going to fail, they’re both going to fail?’ The expression around was they’re going to pancake down, almost vertically. And they did. **It was the only way they could fail. It was inevitable.** And it was horrific.” Asked whether they could have been built in such a way that they would have withstood the impact, he replies: “Bad question - they did withstand the impact. The correct question is could they have been built to withstand the consequences, the fire? […] I’ll defer to the reports coming out, but I will say - is society willing to pay for it? It’s far cheaper to take the battle to terrorists than let them bring it to us.” [New Scientist]

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comes straight down

October 21st, 2004 :: According to *Boulder Weekly*, construction manager for the World Trade Center and University of Colorado civil engineering professor *Hyman Brown* explains that the airplane fuel and the fire-suppression system caused the building to collapse. The fire-suppression system blocks off five-floor blocks so the fire can’t go up or down. The steel in that five-floor area melts. All the tonnage above the five-floor area comes straight down when the steel melts. That broke all the connections, and that caused the building to collapse. [Boulder Weekly]

NIST Draft comments

June 2005 :: After a six-week period for public review of their 10000-page report, *NIST* publishes the “Public Comments Received by NIST on DRAFT Reports”. *John Lyle*, Arup, objects that results from 5 FEM indicate that the natural frequency of the structure is not significantly altered by a large hole in the outer tube and missing parts of the core (p. 197); that the global model ignored that the impact scenario was shorter than the natural period of the towers; misses clarification whether P-Δ effects were taken into account as result from swaying (p. 183) :: *Barbara Lane*, Arup, does not agree with NIST’s conclusion that only impact induced fire proofing damage caused the collapse. Loss of fire proofing may have reduced the time to collapse, but the analysis presented does not prove that it would have prevented collapse, particularly when so much emphasis is placed, in this regard, on the tests carried out. She believes that the repeated statements about fire protection are a little misleading. (pp. 308, 322) :: *Dave Johnston*, BOMA International, asks NIST exactly how many building collapses have there been…..ever? (p. 354) :: Professor *James Quintiere* does not believe that NIST has presented a convincing argument for their collapse hypotheses for WTC 1 and 2. NIST fails to document the rationale for the speedy elimination of the steel in this incident. NIST has not presented clear and sufficient evidence that the aircraft impacts caused the elimination of insulation, especially from the core columns. The NIST report reads like a scientific enterprise using computer simulations that have never been used (or validated) in this way before. The October surprise in the NIST investigation was the assertion that all of the core column insulation was knocked off by the airplane impacts. NIST has relied on state-of-the-art computer models that are at the forefront of their technologies. However, these models have not been proven comprehensively for less complex incidents than the WTC. Can an engine possibly hit a core column without hitting anything on the floor occupancy and structure? That does not seem possible, so how can an engine damage a core colum? The global collapse mechanism of the buildings must be made as clear as possible. A vague answer expressed by the current NIST working hypothesis is not sufficient. If the core of the answers are really revealed and understood, NIST should be able to explain them in simple fundamental physics, and not shroud them in computer graphics. (pp. 374 ff) :: *Jon Magnusson*, PE, SE, Hon. AIA, says NIST has provided absolutely no data showing there has been even a single death as a result of progressive collapse anywhere in the U.S. The consequences of the WTC attack did NOT constitute a case of progressive collapse. The WTC design MET AND BETTERED all currently proposed progressive collapse standards and code provisions (p. 554) [NIST]

NIST: does not actually include

September 2005 :: With the specific objective (p. xxxix) to determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft, *NIST* in the "Federal Building and 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 Tower" examine more than 170 areas on 16 perimeter column panels, but only three columns have evidence that the steel reached temperatures above 250ºC. Only two core column specimens have sufficient paint remaining to make such an analysis, and their temperatures did not reach 250 ºC. Using metallographic analysis, NIST determine that there was no evidence that any of the samples had reached temperatures above 600 ºC (pp. 176-177). In state-of-the-art computer simulations, none of the columns with intact insulation reached temperatures over 300 °C. Only a few isolated truss members with intact insulation were heated to temperatures over 400 °C in the WTC 1 simulations and to temperatures over 500 °C in the WTC 2 simulations. In WTC 1, if the fires had been allowed to continue past the time of building collapse, complete burnout would likely have occurred within a short time since the fires had already traversed around the entire floor, and most of the combustibles would already have been consumed. In WTC 2, if the fire simulation were extended for 2 hours past the time of building collapse with all windows broken, the temperatures in the truss steel on the west side of the building (where the insulation was undamaged) would likely have increased for about 40 min before falling off rapidly as the combustibles were consumed. Temperatures of 700 °C to 760 °C were reached over approximately 15 percent of the west floor area for less than 10 min. Approximately 60 percent of the floor steel had temperatures between 600 °C and 700 °C for about 15 min. Approximately 70 percent of the floor steel had temperatures that exceeded 500 °C for about 45 min. At these temperatures, the floors would be expected to sag and then recover a portion of the sag as the steel began to cool. The temperatures of the insulated exterior and core columns would not have increased to the point where they would have experienced significant loss of strength or stiffness. (p. 184) NIST finds the towers withstood the impacts and would have remained standing were it not for the dislodged insulation and the subsequent multi-floor fires. (p. 174). The focus of the investigation however is on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower. For brevity in the report, this sequence is referred to as the 'probable collapse sequence,' although it (includes little analysis of | does not actually include) the structural behaviour of the tower after the conditions for collapse initiation were reached and collapse became inevitable. (footnotes on pp. xxxvii & 82) [NIST]

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mechanics of progressive collapse: W_g > W_p

June 26th, 2006 :: *Professor Z. P. Bažant* and *Mathieu Verdure*, at the U.S. National Congress of Theoretical and Applied Mechanics, Boulder, Colorado, present "Mechanics of Progressive Collapse: Learning from World Trade Center and Building Demolitions". The destruction of the Towers was not only the largest mass murder in U.S. history, but also a big surprise for the structural engineering profession. No experienced structural engineer watching the attack expected the WTC towers to collapse. No skyscraper has ever before collapsed due to fire. The fact that the WTC towers did, beckons deep examination. Further calculations beyond the 2002 "Simple Analysis" are found superfluous, but a theory describing the progressive collapse dynamics beyond the initial trigger, with the WTC as a paradigm, could still be very useful for other purposes, especially for learning from demolitions. They go on to show that progressive collapse will be triggered if the total (internal) energy loss during the crushing of one story (equal to the energy dissipated by the complete crushing and compaction of one story, minus the loss of gravity potential during the crushing of that story) exceeds the kinetic energy impacted to that story. Regardless of the load capacity of the columns, there is no way to deny the inevitability of progressive collapse driven by gravity alone. Also, some critics are addressed, who have been under the mistaken impression that collapse cannot occur if (because of safety factors used in design) the weight *mg* of the upper part is less than the load capacity *F_0* of the floor, which led them to postulate various strange ideas (such as "fracture wave" and planted explosives). However, since the energy loss up to the point at which the load-deflection diagram intersects the line *F=mg(z)* is smaller than the kinetic energy of the impacting mass *m(z)* (Fig. 3), it is clear that this impression is erroneous. What matters is energy, not strength, nor stiffness. :: **March 2007** the paper will be published in the *Journal of Engineering Mechanics*. [Source]

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super-heated jet fuel

August 21st, 2006 :: *CBC* interviews *Lee Hamilton*, 9/11 Commission co-chair. He says "the engineers and the architects have studied this thing in extraordinary detail, and they can tell you precisely what caused the collapse of those buildings. What caused the collapse of the buildings […] was that the super-heated jet fuel melted the steel super-structure of these buildings and caused their collapse. There's a powerful lot of evidence to sustain that point of view, including the pictures of the airplanes flying into the building." [CBC]

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very high strength steel not allowed to save cost

September 25th, 2006 :: *Karen Auguston Field*, Editor-in-Chief for *Design News*, cites *Abolhassan Astaneh-Asl* explaining at *MSC. Software's* 2006 “Virtual Product Development Conference” that the simulation model shows the plane slicing right through the outer walls of the as-built building like it was a thin soda can. “Because of their unique design and the use of the so called ‘steel bearing wall’ tube structural system, which as far as we know has never been used before or after its application in the WTC towers, the buildings essentially showed no resistance to the impact of a medium-sized plane flying into them at about 450miles per hour. […] the truss joists collapsed first, leaving the exterior columns of probably two floors in the impact area with no bracing but still under gravity load from the floors above. As the columns heated up and reached temperatures of nearly 1,000F, their strength was reduced to less than half the design strength and they started to buckle. When the columns buckled, the top portion of the building, losing its supports, was pulled down by gravity and dropping on the floors below, pancaking the floors one after another and leading to progressive collapse in an almost perfect vertical direction of the pull of gravity force.” He also notes that designers chose to fabricate many of the building columns out of very high strength steel [90 ksi steel as opposed to the more typical 36-65 ksi steel], which is not allowed by the structural design codes then and is still not allowed in current codes. “But the World Trade Center did not need to obtain a permit from City Hall. Because of special status as Port Authority of New York and New Jersey, they could make such choices outside the prevailing codes.” This choice allowed builders to use less steel in the columns [two to three times thinner than typical columns] to save cost. [Design News]

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what did and did not: gravity alone

March 31st, 2008 :: To check whether the recent allegations of controlled demolition, which rest on the free fall hypothesis, have any scientific merit and to prove that they do not, *Z. P. Bažant*, *Jia-Liang Le, Frank R. Greening* and *David B. Benson* present “What Did and Did Not Cause Collapse of WTC Twin Towers in New York”. It is shown that the observed size range (0.01 mm—0.1 mm) of the dust particles of pulverized concrete is consistent with the theory of comminution caused by impact, and that less than 10% of the total gravitational energy, converted to kinetic energy, sufficed to produce this dust — whereas more than 150 tons of TNT per tower would have to be installed to produce the same pulverization. Also, initial speculation that very high temperatures were necessary to explain collapse are revised based on NISTs findings, since steel temperature ≥150°C sufficed to trigger the viscoplastic buckling of columns. To get convinced of the inevitability of gravity driven progressive collapse, further analysis is, for a structural engineer, superfluous, but nevertheless needed to dispel false myths. It is no surprise at all that the towers collapsed essentially on their footprint. Gravity alone must have caused just that. [Source 1, Source 2]

NIST FAQ: multiple factors

September 19, 2011 :: The *NIST FAQ* state that the WTC towers collapsed because: (1) the impact of the planes severed and damaged support columns, dislodged fireproofing insulation coating the steel floor trusses and steel columns, and widely dispersed jet fuel over multiple floors; and (2) the subsequent unusually large number of jet-fuel ignited multi-floor fires (which reached temperatures as high as 1,000 degrees Celsius) significantly weakened the floors and columns with dislodged fireproofing to the point where floors sagged and pulled inward on the perimeter columns. This led to the inward bowing of the perimeter columns and failure of the south face of WTC 1 and the east face of WTC 2, initiating the collapse of each of the towers. Both photographic and video evidence — as well as accounts from the New York City Police Department aviation unit during a half-hour period prior to collapse — support this sequence for each tower. NIST's findings do not support the "pancake theory" of collapse, which is premised on a progressive failure of the floor systems in the WTC towers. Instead, the NIST investigation showed conclusively that the failure of the inwardly bowed perimeter columns initiated collapse and that the occurrence of this inward bowing required the sagging floors to remain connected to the columns and pull the columns inwards. Thus, the floors did not fail progressively to cause a pancaking phenomenon. [NIST] The *NIST FAQ* for WTC 7 clarify that progressive collapse did NOT occur in the WTC towers. First, the collapse of each tower was not triggered by local damage or a single initiating event. Second, the structures were able to redistribute loads from the impact and fire-damaged structural components and subsystems to undamaged components and to keep the building standing until a sudden, global collapse occurred. Had a hat truss that connected the core columns to the exterior frame not been installed to support a TV antenna atop each WTC tower after the structure had been fully designed, it is likely that the core of the WTC towers would have collapsed sooner, triggering a global collapse. Such a collapse would have some features similar to that of a progressive collapse. The Twins were brought on by multiple factors, including structural damage caused by the aircraft impact, extensive dislodgement of the sprayed fire-resistive materials or fireproofing in the impacted region, and a weakening of the steel structures created by the fires. [NIST]

Years later …

all factors

September 21st, 2011 :: According to a theory advanced by materials scientist *Christian J. Simensen* of SINTEF Materials and Chemistry, Norway, a mixture of water from sprinkler systems and molten aluminum from melted aircraft hulls created explosions that led to the collapses of the Twin Towers: both scientific experiments and 250 reported disasters suffered by the aluminium industry have shown that the combination of molten aluminium and water releases enormous explosions. [Science Daily] *Professor Bažant*, according to "New Twin Tower Collapse Model Could Squash 9/11 Conspiracies", thinks that the official explanation suffices, as he had explained it in six papers in leading journals. In his opinion, all factors related to the collapse have been accounted for. [Live Science]

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knew right away

May 20, 2013 :: For "Bringing down the House" *(U.S. News)*, *Michael Satchell* interviews Mark Loizeaux of *CDI*. As experts in buildings' vulnerabilities, they knew right away what few Americans realized. "I told Doug immediately that the tower was coming down, and when the second tower was hit, that it would follow," remembers Mark. The Loizeaux brothers watched first responders streaming into the doomed towers and tried frantically, and unsuccessfully, to phone in warnings. [U.S. News]

Recently

different degrees of ductility, fracturing and end support flexibility

September 4th, 2016 :: In response to experiments by *Korol* and *Sivakumaran*, *Jia-Liang Le* and *Z.P. Bažant* concede that, if the column ends were rigidly supported and if the ductility of steel was unlimited, then the simple plastic three-hinge mechanism with constant bending moments, would have dissipated ~3.5-times as much energy than considered in previous studies, but posit that calibration by matching of the video record of initial collapse implies that this energy must have been reduced to about 2/3 of the energy predicted by the three-hinge model. This estimated 2/3 reduction must have been caused by the fracturing of steel and by the flexibility of spandrel beams which reduced the rotations of the plastic hinges at column ends. With this update of input data, all the observed features of the WTC collapse remain to be closely matched by the gravity-driven mechanics of progressive collapse. [Source]

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collapse must have been spontaneous

February 13th, 2017 :: Responding to an article published earlier by *Europhysics News*, *Jia-Liang Le* and *Z.P. Bažant* reiterate in "Mechanics-based mathematical studies proving spontaneity of post-impact WTC towers collapse" that the towers were designed not to fail due to airplane impact damage – and that they didn't. The progressive collapse must have been spontaneous, gravity-driven, and that after impact, no external weakening of the structure was needed to explain the collapse. The main cause of the total collapse of the towers damaged by impact was a fire of enormous proportions. The kinetic energy of the top part exceeded by an order of magnitude the energy required for complete buckling of all the columns of the cold story. In the lower floors, one story got squashed within mere 0.07 s. The air ejected from the story must have reached, Mach 1. The sonic booms heard, the rapidly expanding dust clouds and the wide ejection of debris are no surprise. From the viewpoint of physics, and structural mechanics in particular, it is perfectly clear that no WTC demolition took place. The collapse was triggered by an atypical fire ignited simultaneously in a large volume. It was driven by gravity, and was spontaneous. In hindsight, it was, under the given circumstances, inevitable. Experience from mining and tunneling shows that such 0.01mm small concrete particles could be produced by explosives only if the alleged authors installed about 150 tons of TNT into small holes drilled into all concrete floor slabs of each tower.

Critics do not explain how such a massive operation, requiring many workers, could have been carried out in secrecy, no one leaking it later to the public. [Europhysics News]

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would still be standing without the fires

September 8th, 2021 :: *Terry Grant* interviews *Barzin Mobasher*, Arizona State University civil engineering professor, for *ASU News*, opines: “Were it not for the fire, engineers could secure the building, strip out the damaged components and repair and retrofit. […] The potential energy stored in the structure due to weight of the building itself at the floor heights was sufficient to create a self-driving and accelerating domino collapse effect much like a landslide that gains speed through the process.” :: [ASU News]

References

Bažant Corpus

Zdeněk P. Bažant, Yong Zhou: “Why Did th World Trade Center Collapse?”; SIAM News Vol 34 No 8 October 13, 2001 https://web.archive.org/web/20070715213036/https://www.siam.org/news/news.php?id=578 / https://web.archive.org/web/20120504023524/http://www.siam.org/pdf/news/578.pdf

405: Zdeněk P. Bažant, Yong Zhou: “Why Did the World Trade Center Collapse?—Simple Analysis”; Journal of Engineering Mechanics 2002; http://www.civil.northwestern.edu/people/bazant/PDFs/Papers/405.pdf

> The original version with Eqs. (1) and (2) was originally submitted to ASCE on **September 13, 2001**

> […] we are not attempting to model the details of the real failure mechanism but **seek only to prove that the towers must have collapsed and do so in the way seen** […]

> The analysis shows that if prolonged heating caused the majority of columns of a single floor to lose their load carrying capacity, **the whole tower was doomed**. The structural resistance is found to be an order of magnitude less than necessary for survival, even though the most optimistic simplifying assumptions are introduced.

> The 110-story towers of the World Trade Center were designed to withstand as a whole the forces caused by a horizontal impact of a large commercial aircraft (Appendix I). So why did a total collapse occur? The cause was the dynamic consequence of the prolonged heating of the steel columns to **very high temperature.**

> If fracturing in the plastic hinges were considered, a still smaller (in fact much smaller) energy dissipation would be obtained. So **the collapse of the tower must be an almost free fall**. This conclusion is supported by the observation that the duration of the collapse of the tower, observed to be 9 s, was about the same as the duration of a free fall in a vacuum from the tower top (416 m above ground) to the top of the final heap of debris (about 25 m above ground), which is `t = √(2(416m-25m)/g) = 8.93s`. It further follows that the brunt of vertical impact must have gone directly into the columns of the framed tube and the core and that any delay Δ*t* of the front of collapse of the framed tube behind the front of collapsing (‘pancaking’) floors must have been negligible, or else the duration of the total collapse of the tower, 9 s + Δ*t*, would have been significantly longer than 9 s. However, even for a short delay Δ*t*, the floors should have acted like a piston running down through an empty tube, which helps to explain the smoke and debris that was seen being expelled laterally from the collapsing tower.

> It will nevertheless be appropriate to initiate research on materials and designs that would postpone the collapse of the building so as to extend the time available for

> evacuation, provide a hardened and better insulated stairwell, or even prevent collapse in the case of a less severe attack such as an off-center impact or the impact of an aircraft containing little fuel.
>
> **The main purpose of the present analysis is to prove that the whole tower must have collapsed if the fire destroyed the load capacity of the majority of columns of a single floor.**

- **D20:** Discussion by K. Sivakumar

  The **stated aim** was to **prove** that the towers **must have collapsed**,

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466: Zdeněk P. Bažant, Mathieu Verdure: “Mechanics of Progressive Collapse: Learning from World Trade Center and Building Demolitions”; Journal of Engineering Mechanics 2007
http://www.civil.northwestern.edu/people/bazant/PDFs/Papers/466.pdf

> Progressive collapse is a failure mode of great concern for tall buildings, and is also typical of building demolitions. The most infamous paradigm is the collapse of the World Trade Center towers.
>
> The destruction of the World Trade Center on September 11, 2001 was not only the largest mass murder in U.S. history but also **a big surprise for the structural engineering profession**, perhaps the biggest since the collapse of the Tacoma Bridge in 1940. **No experienced structural engineer watching the attack expected the WTC towers to collapse. No skyscraper has ever before collapsed due to fire. The fact that the WTC towers did, beckons deep examination.**
>
> [T]he press reports right after September 11, 2001 indicating temperature in excess of 800 °C, turned out to be groundless, but Bažant and Zhou’s analysis did not depend on that.
>
> the upper part of the tower fell, with little resistance, through at least one floor height, impacting the lower part of the tower. This triggered progressive collapse because the kinetic energy of the falling upper part exceeded - by an order of magnitude - the energy that could be absorbed by limited plastic deformations and fracturing in the lower part of the tower.
>
> The kinetic energy of the top part of the tower impacting the floor below was found to be about 8.4 x larger than the plastic energy absorption capability of the underlying story, and considerably higher than that if fracturing were taken into account. This fact, along with the fact that during the progressive collapse of underlying stories the loss of gravitational potential per story is much greater than the energy dissipated per story, was sufficient for Bažant and Zhou to conclude, purely on energy grounds, that **the tower was doomed** once the top part of the tower dropped through the height of one story **or even 0.5 m**.
>
> [N]o further analysis has been necessary to prove that the WTC towers had to fall the way they did, due to gravity alone. However, a theory describing the progressive collapse dynamics beyond the initial trigger, with the WTC as a paradigm, could

nevertheless be very useful for other purposes, especially for learning from demolitions. It could also help to clear up misunderstanding (and thus to dispel the myth of planted explosives). Its formulation is the main objective of what follows.

As W_g [the loss of gravity when the upper part of the tower is moved down by one floor] was, for the WTC, greater than W_p [the area under the complete load-displacement curve] [Fig. 3] by an order of magnitude, acceleration of collapse from one story to the next was ensured. Some critics have been under the mistaken impression that collapse cannot occur if (because of safety factors used in design) the weight *mg* of the upper part is less than the load capacity F_0 of the floor. This led them to postulate various **strange ideas** (such as “fracture wave” and planted explosives).
[…]
If Eq. 5 [`K < W_c`],
> where *K* = kinetic energy of the impacting mass *m(z)* and *W_c* = net energy loss up to *u_c* during the crushing of one story. This is the criterion of preventing progressive collapse from starting [Fig. 4(c)]. Its violation triggers progressive collapse

is violated, there is regardless of [the load-displacement curve of a column] no way to deny the inevitability of progressive collapse driven only by gravity.

Ronan Point apartments, the Oklahoma City bombing, etc., demonstrate that only a vertical slice of building may undergo progressive collapse, whereas the remainder of the building stands. Such a collapse is truly a three-dimensional problem, much harder to analyze, but some cases might allow adapting the present one-dimensional model as an approximation.

1. If the total (internal) energy loss during the crushing of one story (representing the energy dissipated by the complete crushing and compaction of one story, minus the loss of gravity potential during the crushing of that story) exceeds the kinetic energy impacted to that story, collapse will continue to the next story. This is the criterion of progressive collapse trigger [Eq. (5)]. If it is satisfied, **there is no way to deny the inevitability of progressive collapse driven by gravity *alone*** (regardless of by how much the combined strength of columns of one floor may exceed the weight of the part of the tower above that floor). What matters is energy, not the strength, nor stiffness. […]
2. The present idealized model allows simple **inverse analysis** which can yield the crushing energy per story and other properties of the structure **from a precisely recorded history of motion** during collapse. From the crushing energy, one can infer the collapse mode, e.g., single-story or multistory buckling of columns.
3. **It is proposed to monitor the precise time history of displacements in building demolitions**—for example, by radio telemetry from sacrificial accelerometers, or high-speed optical camera—**and to engineer different modes of collapse to be monitored**. This should provide **invaluable information** on the energy absorption capability of various structural systems, needed for assessing the effects of explosions, impacts, earthquake, and terrorist acts.

- **D25:** Discussions by Gregory Szuladzinski, James R. Gourley

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476: Zdeněk P. Bažant, Jia-Liang Le, Frank R. Greening, David B. Benson: “What Did and Did Not Cause Collapse of World Trade Center Twin Towers in New York?”; Journal of Engineering Mechanics 2008 http://www.civil.northwestern.edu/people/bazant/PDFs/Papers/476.pdf);

> Previous analysis of progressive collapse showed that gravity alone suffices to explain the overall collapse of the World Trade Center Towers. However, **it remains to be determined whether the recent allegations of controlled demolition have any scientific merit**. The **present analysis proves that they do not**. The video record available for the first few seconds of collapse is shown to agree with the motion history calculated from the differential equation of progressive collapse but, despite uncertain values of some parameters, it is totally **out of range of the free fall hypothesis, on which these allegations rest**.
>
> But are high steel temperatures really necessary to explain collapse? Not really. The initial speculation that very high temperatures were necessary to explain collapse must be now revised since tests revealed a strong temperature effect on the yield strength of the steel used. The tests by NIST showed that, at temperatures 150 °C, 250 °C and 350 °C, the yield strength of the steel used in the fire stories decreased by 12%, 19% and 25%, respectively. […] Although a detailed computer analysis of columns stresses after aircraft impact is certainly possible, it would be quite tedious and demanding, and has not been carried out by NIST. Nevertheless, it can easily be explained that the stress in some surviving columns most likely exceeded 88% of their cold strength σ_0. In that case, **any steel temperature ≥ 150 °C sufficed to trigger the viscoplastic buckling of columns.**
>
> Merely to be convinced of the **inevitability of gravity driven progressive collapse**, further analysis is, for a structural engineer, superfluous. Further analysis is nevertheless needed to **dispel false myths**, and to acquire full understanding that would allow assessing the danger of progressive collapse in other situations.

- **D27:** Discussion by Anders Björkman

> [discusser] presents no meaningful mechanics argument against the gravity driven progressive collapse model of our paper

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499: Jia-Liang Le, Zdeněk P. Bažant: “Why the Observed Motion History of World Trade Center Towers Is Smooth”; Journal of Engineering Mechanics 2011 http://www.civil.northwestern.edu/people/bazant/PDFs/Papers/499.pdf

> At the moment of impact, the velocity of the upper part must have decreased. The fact that no velocity decrease can be discerned in the videos of the early motion of the tower top has been recently exploited to claim that the collapse explanation generally accepted within the structural mechanics community was invalid. This claim is here shown to be groundless. Calculations show that the velocity drop is far too small to be perceptible in amateur video records and is much smaller than the inevitable error of such video records. […] The collapse of the World Trade Center WTC towers has been explained as a gravity-driven process triggered by the collapse of a critical story heated by fire (Bažant and Zhou 2002; Bažant and Verdure 2007; Bažant et al. 2008; Bažant and Le

2008). **All the objections** of the proponents of the controlled demolition hypothesis **have been shown invalid**.

- **D28:** Discussion by Crockett Grabbe

discusser's […] objections against the analysis of gravity-driven progressive collapse of the Word Trade Center (WTC) towers by [sic] have **no scientific merit**

585: Jia-Liang Le, Zdeněk P. Bažant: "Mechanics of Collapse of WTC Towers Clarifed by Recent Column Buckling Tests of Korol and Sivakumaran"; Int. J. Str. Stab. Dyn. 2016
http://cee.northwestern.edu/people/bazant/PDFs/Papers/585.pdf

> […] Korol and Sivakumaran […] revealed that, under the simplifying assumptions of rigid end supports and unlimited ductility (or no fracturing) of unheated columns, the energy dissipation of the WTC columns would have been at maximum 3.5-times as large as that calculated by the plastic hinge mechanism normally considered for small-deflection buckling. […] The **proper conclusion** from Korol and Sivakumaran's tests, based on close matching of the video record, is that the fracturing of unheated columns and the flexibility of their end restraints must have significantly reduced the energy dissipation in columns calculated under the assumptions of no fracture and no end restraint flexibility.
>
> Previous studies led to a rigorous mathematical model which showed that a gravity driven collapse of the twin towers of the World Trade Center (WTC) in New York on September 11, 2011 was **inevitable**.

625: Jia-Liang Le, Zdeněk P. Bažant; "Spontaneous Collapse Mechanism of World Trade Center Twin Towers and Progressive Collapse in General"; J. Struct. Eng. 2022
http://www.civil.northwestern.edu/people/bazant/PDFs/Papers/624.pdf

> The kinetic energy of the upper falling part was immediately (Bažant 2001) shown to be many time greater than the maximum possible energy absorption capacity of the columns of the underlying story, which made a progressive story-by-story collapse **inevitable**. […]
> For the collapse, the crucial difference from previous fires in tall buildings was that this fire was ignited simultaneously over a large volume of several stories. This caused the surface-to-volume ratio of the fire zone to be much smaller than in previous fires, which reduced the cooling rate and thus led to higher temperatures (normally the fire moves—when a neighboring place starts burning, the previous one is already cooling).
> NIST's analysis supports Bažant and Zhou's (2002) conclusion that as soon as the top part of each tower fell through the height of at least one story, the whole tower was doomed to suffer a total collapse (NIST 2005). […]
> Of course, a detailed numerical modeling of the entire collapse process, with finite-element discretization of all columns and floors and gas flows, would have been computationally infeasible. But such a brute-force approach has actually been shown unnecessary.
> The fact that the stories were numerous and that the collapse was vertical and almost

> simultaneous over the full tower width made possible a simplified, although realistic, one-dimensional (1D) continuum analysis. A 1D continuum model for the vertical collapse propagation of the crush front was developed by Bažant and Verdure (2007). They applied d'Alembert's principle to formulate the dynamic equilibrium of the upper falling part, and then to derive the equations for the crush-down and crush-up phases of the collapse process.
> In the subsequent studies, the model was further refined by incorporating different energy dissipation sources, such as the impact comminution of concrete slabs, fast ejection of air, and lateral ejection of debris (Bažant et al. 2008; Le and Bažant 2011, 2017a). The model was shown to match all the observations, which include video records of the motion of the upper falling part during the first few seconds of the collapse (before dust clouds obscured the view), the total collapse duration inferred from the seismic record, the particle-size distributions of the dynamically comminuted concrete floors, the explosive expansion of dust clouds, and the booms heard. This analysis dispelled all the main claims of the proponents of the controlled demolition hypothesis, which include the free-fall motion of the tower, pulverization of concrete slabs by explosives, wide spreading of concrete particles, and dust burst and booms supposedly due to explosions. The analysis showed them all to be false.

EPN: Jia-Lang Le, Zdeněk P. Bažant: "Mechanics-Based Mathematical Studies Proving Spontaneity of Post-Impact WTC Towers Collapse"; Europhysics News 48/1, January 2017
https://www.europhysicsnews.org/articles/epn/abs/2017/01/epn2017481p18/epn2017481p18.html

> The cause of collapse of the World Trade Center (WTC) in New York on 9/11/2001, clarified mathematically by mechanical analysis, has been questioned by some **lay critics without any meaningful calculations**. They blame the collapse on controlled demolition, implying some sort of conspiracy. […]
> The **sonic booms heard, the rapidly expanding dust clouds and the wide ejection of debris are no surprise** (while **some critics erroneously** claimed that the booms could have been caused only by explosives). The size distribution of concrete particles, calculated from the energy of impact on floor slabs, matches the distribution of the particle sizes seen on the ground, which ranged from 0.01 mm up.
> The critics claimed that such small particles could be produced only by explosives. Yet the experience from mining and tunneling […] shows that such small particles could be produced by explosives only if the alleged authors installed about 150 tons of TNT into small holes drilled into all concrete floor slabs of each tower. The **critics do not explain how such a massive operation, requiring many workers, could have been carried out in secrecy, no one leaking it later to the public. Many workers would have been needed even for the usual demolition by explosives installed on the columns of one story**, and, to match the collapse progression as seen, the aircraft would have had to impact each tower just above the story wired by explosives.

- Zdeněk P. Bažant, Mathieu Verdure, Yong Zhou, Frank R. Greening, David B. Benson: PRESENTATION: "Mechanics of Progressive Collapse: What Did And Did Not Doom World Trade Center, And What Can We Learn?" Georgia Tech / Northwestern April 4 &

> May 24, 2007 https://www.slideserve.com/sawyer/mechanics-of-progressive-collapse-what-did-and-did-not-doom-world-trade-center-and-what-can-we-learn

> Thermite cutter charges planted? — evidenced by residues of S, Cu, Si found in dust? But these must have come from gypsum wallboard, electrical wiring, galvanized sheet steel, etc. […]
> “Fracture Wave” allegedly propagated in a material pre-damaged, e.g. by explosives, led to free-fall collapse — unrealistic hypothesis, because: A uniform state on the verge of material failure cannot exist in a stable manner, because of localization instability. […]
> MAIN RESULTS: All WTC observations are explained. All lay criticisms are refuted.

9/11 Commission

National Commission on Terrorist Attacks Upon the United Dates: “9/11 Commission Report”; 2004 http://govinfo.library.unt.edu/911/report/index.htm

> [the] exterior walls bore most of the weight of the building. The interior **core of the buildings was a hollow steel shaft**, in which elevators and stairwells were grouped.

NIST

John Lyle, ARUP: National Institute for Standards and Technology, “Public Comments Received by NIST on DRAFT Reports”; http://www.nist.gov/el/disasterstudies/wtc/upload/CombinedPublicCommentsDraftTowersReports2005-2.pdf

> ***Simplistic Model Results***
> Results from five simple finite element models (of roughly the same geometric proportions as WTC1 and WTC2) demonstrate that a large hole in the side of a tube and the missing parts of the core do not significantly influence the natural frequency (see table 1).

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
	Tube & core, No holes	Large hole in side & no core	No hole with core	Large hole in side with core	Large hole in side and core missing at same level
Bending	0.1653	0.1647	0.1643	0.1636	0.1637
Torsion	0.5981	0.5889	0.5981	0.5891	0.5889

^(**Table 1** Variation of natural frequency in Hz)^

> ***Comment reason:*** The stability of the towers immediately following the impact has not really been proven by the impact analysis. Simply taking the results of the impact damaged structure and loading it statically effectively ignores and [sic] damage that may have resulted due to swaying.
> ***Revision suggestion:*** Provide a more detailed analysis to take account of load path re-distribution in the core and the P-Δ effects of sway following the impact. *(PDF p. 197)*

NCSTAR-1

National Institute for Standards and Technology: "Federal Building and 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 **(NCSTAR 1)**"; September 2005
https://www.nist.gov/el/final-reports-nist-world-trade-center-disaster-investigation

> The specific objectives were:
>
> 1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed. […] *(NCSTAR 1, p. xxxix)*
>
> The focus of the investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower. For brevity in this report, this sequence is referred to as the 'probable collapse sequence,' although it **includes little analysis** of the structural behaviour of the tower after the conditions for collapse initiation were reached and **collapse became inevitable**. *(NCSTAR 1, p. xxxvii (footnote))*
>
> At 9:30 a.m., EMS set up a triage desk in the lobby of WTC 2. *(NCSTAR 1, p. 44)*
>
> NIST performed confirmatory tests on samples of the **236 pieces of recovered steel** to determine if the steel met the structural specifications. *(NCSTAR 1, p. 68)*
>
> The focus of the Investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower. For brevity in this report, this sequence is referred to as the "probable collapse sequence," although it **does not actually include** the structural behavior of the tower after the conditions for collapse initiation were reached and **collapse became inevitable**. *(NCSTAR 1, p. 82 (footnote))*
>
> Over a period of about 18 months, **236 pieces of steel** were shipped to the NIST campus, […] The remaining 229 samples **represented roughly 0.25 percent to 0.5 percent of the 200,000 tons of structural steel** used in the construction of the two towers. *(NCSTAR 1, p. 87)*
>
> Examination of photographs showed that 16 of the exterior panels recovered from WTC 1 were exposed to fire prior to the building collapse. None of the nine recovered panels from within the fire floors of WTC 2 were directly exposed to fire. NIST used two methods to estimate the maximum temperatures that the steel members had reached: Observations of paint cracking due to thermal expansion. Of the more than 170 areas examined on 16 perimeter column panels, only three columns had evidence that the steel reached temperatures above 250 °C: east face, floor 98, inner web; east face, floor 92, inner web; and north face, floor 98, floor truss connector. Only two core column specimens had sufficient paint remaining to make such an analysis, and their **temperatures did not reach 250 °C**. NIST did not generalize these results, since the examined columns represented only 3 percent of the perimeter columns and 1 percent of the core columns from the fire floors.

Observations of the microstructure of the steel. High temperature excursions, such as due to a fire, can alter the basic structure of the steel and its mechanical properties. Using metallographic analysis, NIST determined that **there was no evidence that any of the samples had reached temperatures above 600 ºC**. *(NCSTAR 1, p.90)*

6.14.2 Results of Global Analysis of WTC 1

Once the upper building section began to move downwards, the weakened structure in the impact and fire zone was not able to absorb the **tremendous energy** of the falling building section and **global collapse ensued.** *(NCSTAR 1, p.145)*

6.14.3 Results of Global Analysis of WTC 2

[…] As with WTC 1, once the upper building section began to move downwards, the weakened structure in the impact and fire zone was not able to absorb the tremendous energy of the falling building section and **global collapse ensued**. […]
Since the stories below the level of collapse initiation provided little resistance to the **tremendous energy released by the falling building mass**, the building section above came down **essentially in free fall**, as seen in videos. As the stories below sequentially failed, the falling mass increased, further increasing the demand on the floors below, which were unable to arrest the moving mass. *(NCSTAR 1, p.146)*

NIST found no corroborating evidence for alternative hypotheses suggesting that the WTC towers were brought down by controlled demolition using explosives planted prior to September 11, 2001. […] Instead, photographs and videos from several angles clearly show that the collapse initiated at the fire and impact floors and that the collapse progressed from the initiating floors downward, until the dust clouds obscured the view. *(NCSTAR 1, pp.xxxviii, 146 & 176)*

The towers **likely would not have collapsed** under the combined effects of aircraft impact and the subsequent multi-floor fires encountered on September 11 if the thermal insulation had not been widely dislodged or had been only minimally dislodged by aircraft impact. *(NCSTAR 1, p.149)*

6.14.7 & .8 Probable WTC [1|2] Collapse Sequence

The downward movement of this structural block was more than the damaged structure could resist, and the **global collapse began**. *(NCSTAR 1, pp 151 & 152)*

The two aircraft hit the towers at high speed and did considerable damage to principal structural components (core columns, perimeter columns, and floors) that were directly impacted by the aircraft or associated debris. However, **the towers withstood the impacts and would have remained standing** were it not for the dislodged insulation and the subsequent multi-floor fires. *(NCSTAR 1, p. 174)*

Both towers withstood the significant structural damage to the exterior walls, core columns, and floor systems due to the aircraft impact. WTC 2 was the more severely damaged building and the first to collapse. WTC 2 **displayed significant reserve capacity, as evidenced by a post-impact rooftop sway that was more than one-third of that under the hurricane force winds for which the building was designed.** The **oscillation period of this swaying was nearly equal to that calculated for the**

undamaged structure. […] The initial **jet fuel fires** themselves **lasted at most a few minutes.** *(NCSTAR 1, p.182)*

Jet fuel sprayed onto the surfaces of typical office workstations **burned away within a few minutes**. The jet fuel accelerated the burning of the workstation, but did not significantly affect the overall heat released.
In the simulations, none of the columns with intact insulation reached temperatures over 300 °C. Only a few isolated truss members with intact insulation were heated to temperatures over 400 °C in the WTC 1 simulations and to temperatures over 500 °C in the WTC 2 simulations. In WTC 1, **if the fires had been allowed to continue past the time of building collapse, complete burnout would likely have occurred within a short time** since the fires had already traversed around the entire floor, and most of the combustibles would already have been consumed. In WTC 2, if the fire simulation were extended for 2 hours past the time of building collapse with all windows broken, the temperatures in the truss steel on the west side of the building (where the insulation was undamaged) would likely have increased for about 40 min before **falling off rapidly** as the **combustibles were consumed**. Temperatures of 700 °C to 760 °C were reached over approximately 15 percent of the west floor area for less than 10 min. Approximately 60 percent of the floor steel had temperatures between 600 °C and 700 °C for about 15 min. Approximately 70 percent of the floor steel had temperatures that exceeded 500 °C for about 45 min. At these temperatures, the floors would be expected to sag and then recover a portion of the sag as the steel began to cool. The temperatures of the insulated exterior and core columns **would not have increased to the point where they would have experienced significant loss of strength or stiffness**.
(NCSTAR 1, p. 184)

[…t]he simulations were insensitive to both the amount and distribution of the jet fuel. Sensitivity studies showed that the **amount of fuel spilled in the simulation only influenced the results of the first few minutes**; the long-term behavior of the simulated fires was unaffected. *:: NCSTAR 1-5F, p.56*

Northwestern University

The study performed by Northwestern University (Bazant 2002) was a simplified approximate analysis of the overall collapse of the WTC towers which addressed the question of why a total collapse occurred. The analysis addressed the results of prolonged heating which would have caused the columns of a single floor to lose their load carrying capacity and initiated the collapse of the building. The analysis assumed loss of thermal insulation during impact, uniform temperatures of 800 °C for a uniform column size and load across a single floor, and creep buckling and loss of load carrying capacity in over half of the columns. The analysis included evaluation of the dynamic amplification of the loads and the ability of the columns in the lower floors to dissipate the kinetic energy of the falling upper building mass through formation of plastic hinge mechanisms. The analysis found that the ratio of the kinetic energy of the upper building section dropping one floor to the deformation energy of plastic hinge rotation in the lower building columns was approximately a factor of eight.
The study by Northwestern did not address the details of impact damage, fire dynamics,

or structural response of the towers. Rather, **a generalized condition was assumed of heated columns**, and the question of why there was total collapse was addressed. NIST agrees with the assessment of the tower's required structural capacity to absorb the released energy of the upper building section as it began to fall as an approximate lower bound. The likelihood of the falling building section aligning vertically with the columns below was small, given the observed tilting, so that the required capacity would be greater if interaction with the floors was also considered, as pointed out in the study. *(NCSTAR 1-6, p.323)*

The buildings **would likely not have collapsed** under the combined effects of aircraft impact and the subsequent jet-fuel ignited multi-floor fires, **if the insulation had not been dislodged** or had been only minimally dislodged by aircraft impact. The existing condition of the insulation prior to aircraft impact and the insulation thickness on the WTC floor system did not play a significant role in initiating collapse on September 11, 2001. *(NCSTAR 1-6, p.327)*

NIST FAQ

https://www.nist.gov/world-trade-center-investigation/study-faqs/wtc-towers-investigation

10. Why didn't NIST fully model the collapse initiation and propagation of the WTC towers?

The first objective of the NIST WTC investigation included determining why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft (see NIST NCSTAR 1). Determining the sequence of events leading up to collapse initiation was critical to fulfilling this objective. Once the collapse had begun, the propagation of the collapse was readily explained without the same complexity of modeling.

28. Why didn't NIST consider a "controlled demolition" hypothesis with matching computer modeling and explanation like it did for the "pancake theory" hypothesis?

NIST's findings **do not support the "pancake theory"** of collapse, which is premised on a progressive failure of the floor systems in the WTC towers (the composite floor system—that connected the core columns and the perimeter columns—consisted of a grid of steel "trusses" integrated with a concrete slab; see diagram). Instead, the NIST investigation showed conclusively that the failure of the inwardly bowed perimeter columns initiated collapse and that the occurrence of this inward bowing required the sagging floors to remain connected to the columns and pull the columns inwards. Thus, the floors did not fail progressively to cause a pancaking phenomenon. […]
NIST **found no corroborating evidence** for alternative hypotheses suggesting that the WTC towers were brought down by controlled demolition using explosives.

29. Did the NIST investigation look for evidence of the WTC towers being brought down by controlled demolition? Was the steel tested for explosives or thermite residues?

NIST **did not test for the residue of these compounds** in the steel.

31. How could the WTC towers collapse in only 11 seconds (WTC 1) and 9 seconds (WTC 2)—speeds that approximate that of a ball dropped from similar height in a vacuum (with no air resistance)?

[…] Since the stories below the level of collapse initiation **provided little resistance to the tremendous energy** released by the falling building mass, the building section above came down **essentially in free fall**, as seen in videos. […]

34. Why didn't the NIST investigation consider reports of molten steel in the wreckage from the WTC towers?

The **condition of the steel in the wreckage** of the WTC towers (i.e., whether it was in a molten state or not) **was irrelevant to the investigation of the collapse** since it does not provide any conclusive information on the condition of the steel when the WTC towers were standing.

NIST Correspondence

Catherine S. Fletcher: NIST response to request for correction; September 2007
https://www.journalof911studies.com/volume/2007/NISTresponseToRequestForCorrectionGourleyEtal2.pdf

> […W]e are **unable to provide a full explanation of the total collapse**. […] NIST has stated that it found no corroborating evidence to suggest that explosives were used to bring down the buildings. NIST **did not conduct tests for explosive residue** […] such tests would not necessarily have been conclusive

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Patrick Gallagher: "Finding regarding Public Safety Information"; July 9, 2009
http://wayback.archive.org/web/20140415115126/http://cryptome.org/nist070709.pdf

- […] disclosure might jeopardize public safety […] NIST shall not release the following information: [ANSYS collapse initation model, Excel spreadsheets, LS-DYNA global collapse model]

Independent Analysis

Thomas W. Eagar, Christopher Musso: "Why Did the World Trade Center Collapse? Science, Engineering, and Speculation", JOM 2001 > when multiple members fail, the shifting loads eventually overstress the adjacent members and the collapse occurs like a row of dominoes falling down.

Frank Greening: "Energy transfer in the WTC collapse";
https://www.researchgate.net/publication/228801720_Energy_transfer_in_the_WTC_collapse / https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=bcad07a4b3975c6c9c098abffb516df56bb54657

> […] total collapse of both towers would have occurred even without the jet fuel fires.

A.S. Usmani, Y.C. Chung, J.L. Torero: “How Did The WTC Towers Collapse: A New Theory”: Fire Safety Journal, Vol 38 Issue 6 October 2003 https://era.ed.ac.uk/server/api/core/bitstreams/6dcfefb6-7f5a-412e-94b5-6bb06114e5b5/content

1. The analysis presented points to a compelling **fire induced collapse mechanism rather unique to the type of structure** that the WTC Twin-Towers represented
2. This analysis also shows that the collapse is initiated principally by a stability mechanism as a result of geometry changes in the structure caused by thermal expansion effects
3. Furthermore it is quite possible that the geometric changes required to precipitate collapse could result from very low temperatures not high enough to induce significant reduction in the material properties
4. It can therefore be provisionally concluded that these buildings **could have collapsed as a result of a major fire event**. This is of course assuming that any of the active fire suppression systems would either fail or be unable to control the development of the fire. This is a normal assumption when designing fire protection for buildings

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K.A. Seffen: “Progressive Collapse of the World Trade Centre: a Simple Analysis”; Journal of Engineering Mechanics Volume 134, Issue 2 February 1, 2008 https://ascelibrary.org/doi/10.1061/%28ASCE%290733-9399%282008%29134%3A2%28125%29

> The collapse behavior of the World Trade Center towers is considered formally as a propagating instability phenomenon.

- Discussion by Crockett Grabbe: March 15, 2010 https://ascelibrary.com/doi/10.1061/(ASCE)EM.1943-7889.0000025#core-collateral-c5

Wei-Jian Yi, Fan Yi, Yun Zhou: “Experimental Studies on Progressive Collapse Behavior of RC Frame Structures: Advances and Future Needs”; International Journal of Concrete Structures and Materials July 16th, 2021 https://link.springer.com/article/10.1186/s40069-021-00469-6

> some demolition experiments suggested that **resistance of actual buildings** subjected to multi-column removal **could be higher than anticipated** because of the collaboration of several load-resisting mechanisms.

G. Szuladziński: “Temporal considerations in collapse of WTC Towers”: Int. J. Structural Engineering 2012 https://www.researchgate.net/publication/264817987_Temporal_considerations_in_collapse_of_WTC_Towers

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Physical Evidence

Scott Gabriel Knowles: “Lessons in the rubble: The world trade center and the history of disaster investigations in the United States”; History and Technology 2003 https://intel-writers.us/wp-content/uploads/2019/11/Lessons-in-the-rubble-The-world-trade-center-and-the-history-of-disaster-investigations-in-the-United-States.pdf

> In the key first few weeks after the September 11 attacks, the FEMA/ASCE team was not granted full access to the disaster site.

David Kohn: “Culling Through Mangled Steel”; CBS March 7, 2002 https://web.archive.org/web/20150112015313/http://www.cbsnews.com/news/culling-through-mangled-steel/

> **Professor Abolhassan Astaneh-Asl (UC Berkeley structural engineer):** “When there is a car accident and two people are killed, you keep the car until the trial is over… If a plane crashes, not only do you keep the plane, but you assemble all the pieces, take it to a hangar, and put it together. That’s only for 200, 300 people, when they die. In this case you had 3,000 people dead. You had a major machine, a major manmade structure. My wish was that we had spent whatever it takes, maybe $50 million, $100 million, and maybe two years, **get all this steel, carry it to a lot. Instead of recycling it, put it horizontally, and assemble it.** You have maybe 200 engineers, not just myself running around trying to figure out what’s going on. After all, **this is a crime scene** and **you have to figure out exactly what happened for this crime, and learn from it.**“

Bill Manning: “$elling Out The Investigation”; fireengineering.com January 1, 2002 https://web.archive.org/web/20120805233857/http://www.fireengineering.com/articles/print/volume-155/issue-1/departments/editors-opinion/elling-out-the-investigation.html

> For more than three months, structural steel from the World Trade Center has been and continues to be cut up and sold for scrap. Crucial evidence that could answer many questions about high-rise building design practices and performance under fire conditions is on the slow boat to China, perhaps never to be seen again in America until you buy your next car. […]
> Such destruction of evidence shows the astounding ignorance of government officials to the value of a **thorough, scientific investigation of the largest fire-induced collapse in world history.** […]
> Fire Engineering has good reason to believe that the “official investigation” blessed by FEMA and run by the American Society of Civil Engineers is **a half-baked farce** that may already have been commandeered by political forces whose primary interests, to put it mildly, lie far afield of full disclosure. Except for the marginal benefit obtained from a three-day, visual walk-through of evidence sites conducted by ASCE investigation committee members-described by one close source as a “tourist trip”-**no one’s checking the evidence for anything**. […]
> Maybe we should live and work in planes. That way, if disaster strikes, we will at least be sure that a thorough investigation will help find ways to increase safety for our survivors. […]

> Based on the incident's magnitude alone, a **full-throttle, fully resourced, forensic investigation is imperative**. More important, from a moral standpoint, for the safety of present and future generations who live and work in tall buildings-and for firefighters, always first in and last out-the **lessons about the buildings' design and behavior in this extraordinary event must be learned and applied in the real world**. […]
> To treat the September 11 incident any differently would be the **height of stupidity and ignorance**.
> The destruction and removal of evidence must stop immediately.

"WTC scrap sails for India, China"; Daily News January 2002 https://web.archive.org/web/20020223145930/http://origin.dailynews.lk/2002/01/22/wor02.html

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Nityanand Jayaraman & Kenny Bruno: "Trading in Disaster - World Trade Center Scrap Lands in India"; corpwatch.org http://www.corpwatch.org/article.php?id=1608

"India recycles Ground Zero rubble"; BBC News January 17, 2002 https://web.archive.org/web/20040615003107/http://news.bbc.co.uk/2/hi/south_asia/1766693.stm

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"Baosteel Will Recycle World Trade Center Debris"; china.org.cn January 24, 2002 http://www.china.org.cn/english/2002/Jan/25776.htm

> New York authorities' decision to ship the twin towers' scrap to recyclers has raised the **anger of victims' families and some engineers** who believe the massive girders should be further examined to help determine how the towers collapsed.
> But New York Mayor Mike Bloomberg insisted there are better ways to study the tragedy of September 11.
> "If you want to take a look at the construction methods and the design, **that's in this day and age what computers do**," said Bloomberg, a former engineering major. "**Just looking at a piece of metal generally doesn't tell you anything.**"

Asit Jolly: "September 11 steel recycled"; BBC News September 11, 2002 https://web.archive.org/web/20040728114646/http://news.bbc.co.uk/2/hi/south_asia/2250983.stm

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"Scrap Metal from World Trade Center Memorializes September 11 Around the World"; Scrapware.com September 6, 2022 https://www.scrapware.com/blog/scrap-metal-from-world-trade-center-memorializes-september-11-around-the-world/

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Hans J. Herrmann, Stéphane Roux: “Statistical models for the fracture of disordered media”; North-Holland 1990 https://books.google.de/books?id=QufMBQAAQBAJ

William Isaac Newman, S. Leigh Phoenix: “Time-dependent fiber bundles with local load sharing”; Physical Review E January 2001 https://www.researchgate.net/publication/12025109_Time-dependent_fiber_bundles_with_local_load_sharing
https://www.researchgate.net/publication/235745896_Time-dependent_fiber_bundles_with_local_load_sharing_II_General_Weibull_fibers

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https://people.uncw.edu/borretts/courses/bio534/readings/Oreskes1994_verification_validation_confirmation_of_numerical_models_in_the_earth_science.pdf

Steven H. Strogatz: “Exploring complex Networks”; Nature 2001
https://www.nature.com/articles/35065725

T. Bart Quimby: “A Beginner’s Guide to the Steel Construction Manual, 15th ed.”; 2006
https://www.bgstructuralengineering.com/BGSCM15/Contents.htm

Alfred Böge: “Mechanik und Festigkeitslehre”; Vieweg 1992
https://books.google.de/books/about/Mechanik_und_Festigkeitslehre.html?id=AU1iAAAAMAAJ

Richard Feynman:
“Cargo Cult Science”; Caltech commencement address 1974
https://web.archive.org/web/20050304032544/http://neurotheory.columbia.edu/~ken/cargo_cult.html

> There is one feature I notice that is generally missing in cargo cult science. … It’s a kind of scientific integrity, a principle of scientific thought that corresponds to a kind of utter honesty — a kind of leaning over backwards. For example, if you’re doing an experiment, you should **report everything that you think might make it invalid — not only what you think is right about it**; other causes that could possibly explain your results; and things you thought of that you’ve eliminated by some other experiment, and how they worked — to make sure the other fellow can tell they have been eliminated.
> **Details that could throw doubt on your interpretation must be given**, if you know them. You must **do the best you can** — if you know anything at all wrong, or possibly wrong — to explain it. If you make a theory, for example, and advertise it, or put it out,

> then **you must also put down all the facts that disagree with it**, as well as those that agree with it. There is also a more subtle problem. When you have put a lot of ideas together to make an elaborate theory, you want to make sure, when explaining what it fits, that those things it fits are not just the things that gave you the idea for the theory; but that the finished theory makes something else come out right, in addition.
> In summary, the idea is to try to give all of the information to help others to judge the value of your contribution; **not just the information that leads to judgement in one particular direction or another**.

> Science is the belief in the ignorance of experts.
— *Richard Feynman: What is Science?, The Physics Teacher, volume 7, issue 6 (1969), p. 313-320*

Henry Petroski: "Design Paradigms: Case Histories of Error and Judgment"; Cambridge University Press May 27 1994 https://books.google.de/books/about/Design_Paradigms.html?id=C_ZroS6rY54C

> So **when a structure collapses or a design fails to live up to its promise, the lesson should be accessible to all**, and even a jury of laypersons is presumed capable of ruling on culpability.

Ulrich BECK:
"Risk Society: Towards a New Modernity"; Sage Publications 1992
https://books.google.de/books/about/Risk_Society.html?id=W2sDTHaSiiYC

> All decisions on the risks and hazards of civilization falling within the compass of knowledge production are neveer just questions of the substance of knowledge […] They are *at the same time* also decisions on *who is afflicted*, the extent and type of hazard, the elements of the threat, the population concerned, delayed effect, measures to be taken, those responsible, and claims for compensation […] This makes it clear *that the margins for scientific research become narrower and narrower as the threatening potential increases*. […] The destructive forces scientists deal with in all fields today impose on them the inhuman law of *infallibility*. Nto only is it one of the most human of all qualities to break this law, but the law itself stands in clear contradiction science's ideals of progress and critique (*p. 54*)

NFPA 921: "Guide for Fire and Explosion Investigations"; https://www.nfpa.org/codes-and-standards/nfpa-921-standard-development/921

> **Chapter 4: Basic Methodology**
> **4.1 Nature of Fire Investigations.** A fire or explosion investigation is a complex endeavor involving skill, technology, knowledge, and science. The compilation of factual data, as well as an analysis of those facts, **should be accomplished objectively and truthfully**. The basic methodology of the fire investigation should rely on the use of a **systematic approach and attention to all relevant details**. The use of a

systematic approach often will uncover new factual data for analysis, which **may require previous conclusions to be reevaluated**. With few exceptions, the proper methodology for a fire or explosion investigation is to first determine and establish the origin(s), then investigate the cause: circumstances, conditions, or agencies that brought the ignition source, fuel, and oxidant together.
4.2 Systematic Approach. The systematic approach recommended is that of the **scientific method**, which is used in the physical sciences. This method provides for the organizational and analytical process desirable and necessary in a successful fire investigation.
4.3 Relating Fire Investigation to the Scientific Method. The scientific method (see Figure 4.3) is **a principle of inquiry that forms a basis for legitimate scientific and engineering processes**, including fire incident investigation. It is applied using the following steps […]

22.2.4 Exotic Accelerants. Mixtures of fuels and Class 3 or Class 4 oxidizers (see NFPA 430, Code for the Storage of Liquid and Solid Oxidizers) may produce an exceedingly hot fire and may be used to start or accelerate a fire. Thermite mixtures also produce exceedingly hot fires. Such accelerants generally leave residues that may be visually or chemically identifiable.

22.4.9.3.7 Extremism. Extremist-motivated firesetting is committed to further a social, political, or religious cause. Fires have been used as a weapon of social protest since revolutions first began. Extremist firesetters may work in groups or as in-dividuals. Also, due to planning aspects and the selection of their targets, extremist firesetters generally have a great degree of organization, as reflected in their use of more elaborate ignition or incendiary devices. Subcategories of extremist firesetting are terrorism and riot/civil disturbance. **(A) Terrorism.** The targets set by terrorists may appear to be at random; however, target locations are generally selected with some degree of political or economic significance. Political targets generally include government offices, newspapers, universities, political party headquarters, and military or law enforcement installations. Political terrorists may also target diverse properties such as animal research facilities or abortion clinics. Economic targets may include business offices, distribution facilities of utility providers (e.g., atomic generation plants), banks, or companies thought to have an adverse impact on the environment. Fires or explosions become a means of creating confusion, fear, or anarchy. The terrorist may include fire as but one of a variety of weapons, along with explosives, used in furthering his or her goal.

Quassim Cassam: “Vice Epistemology”; he Monist Vol 99, Issue 2 April 2016
https://academic.oup.com/monist/article/99/2/159/2563406

Willem de Lint: “Criminology 9/11”; Globalizations Vol 17, 2020 October 2 2019
https://www.tandfonline.com/doi/full/10.1080/14747731.2019.1655933

Popular

Mario Salvadori: “Building: The Fight Against Gravity”; Atheneum 1979
https://www.google.de/books/edition/Building/ek2kdx3RuLIC

Mario Salvadori: “Why Buildings Stand Up: The Strength of Architecture”; McGraw-Hill 1982
https://www.google.de/books/edition/Why_Buildings_Stand_Up/fUBSAAAAMAAJ

Matthys Levy, Mario Salvadori: “How Buildings Fall Down: How Structures Fail” WW Norton 2002 https://www.google.de/books/edition/Why_Buildings_Fall_Down/Bwd-MHINMGsC

Tom Harris: “How Building Implosions Work”; howstuffworks.com 2010
https://web.archive.org/web/20100805045405/https://science.howstuffworks.com/engineering/structural/building-implosion.htm

> Sometimes, though, a building is surrounded by structures that must be preserved. In this case, the blasters proceed with a true implosion, demolishing the building so that it collapses straight down into its own footprint (the total area at the base of the building). **This feat requires such skill that only a handful of demolition companies in the world will attempt it.**

Kostack Studio: “WTC Simulation 2025, Part 1 (South Tower)”; September 26, 2025
https://www.youtube.com/watch?v=WpHXj62Ylw0

Jean-François Milleron, Daniel Rieber: “Method of demolition by jacking, chassis for (a) jack(s) and thrusting and bracing apparatuses”; European Patent Office March 9, 2012
https://patents.google.com/patent/EP2817466B1/en

> L’invention concerne un procédé de démolition d’immeuble par **vérinage**.

Hevesh5: “World Record Domino Structure DESTROYED by Squirrel!”; August 31, 2024
https://www.youtube.com/watch?v=Ejuf7f20okc

“NEW World Record: 240,000 Domino Planks! (The Imaginary City)”; August 30, 2024
https://www.youtube.com/watch?v=qVS4vaNfPlQ

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https://www.youtube.com/watch?v=Ni70KXe5jPo

Mick West: “Towards A Replicable Physical Model Illustrating Aspects of the Collapse of The WTC Towers on 9/11”; metabunk.org March 15, 2016 https://www.metabunk.org/threads/towards-a-replicable-physical-model-illustrating-aspects-of-the-collapse-of-the-wtc-towers-on-9-11.7396/ / https://www.youtube.com/watch?v=flo62pdaIMI

Precedents

Windsor Tower Madrid 2005 https://en.wikipedia.org/wiki/Windsor_Tower

Plasco Building Tehran 2017 https://en.wikipedia.org/wiki/Plasco_Building

One Meridian Plaza Philadelphia 1991 https://en.wikipedia.org/wiki/One_Meridian_Plaza

Ronan Point London 1968 https://en.wikipedia.org/wiki/Ronan_Point

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Science of Collapse

Bruce R. Ellingwood, Donald O. Dusenberry: “Building Design for Abnormal Loads and Progressive Collapse”; Computer-Aided Civil and Infrastructure Engineering Volume 20, Issue 3 May 2005 https://onlinelibrary.wiley.com/doi/10.1111/j.1467-8667.2005.00387.x

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Theodor Krauthammer: “Modern Protective Structures”; CRC Press February 2008 https://www.taylorfrancis.com/books/mono/10.1201/9781420015423/modern-protective-structures-theodor-krauthammer-theodor-krauthammer

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C. G. Bailey, D. B. Moore: “The Structural Behaviour of Steel Frames with Composite Floorslabs Subject to Fire”; The Structural Engineer Vol 78, Issue 11 2000 https://www.istructe.org/journal/volumes/volume-78-(published-in-2000)/issue-11/the-structural-behaviour-of-steel-frames-with-comp/

Michael Byfield, Wjesundara Mudalige, Colin Morison, Euan Stoddart: “A review of Progressive Collapse research and regulations”; Proceedings of the Institution of Civil Engineers - Structures and Buildings August 01, 2014 https://www.emerald.com/jstbu/article-abstract/167/8/447/408815/A-review-of-progressive-collapse-research-and?redirectedFrom=fulltext / https://eprints.soton.ac.uk/372116/2/ICE_20SB_20Prog_20_20Collapse.pdf

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Uwe Starossek: “Progressive Collapse of Structures”; ICE Publishing 2009 https://www.emerald.com/books/book/18999/Progressive-Collapse-of-Structures

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Edgar V Leyendecker, Bruce R Ellingwood: “Design methods for reducing the risk of progressive collapse in buildings:”; Building Science Series, NIST 1977 https://www.nist.gov/publications/design-methods-reducing-risk-progressive-collapse-buildings

> The normal design process results in a certain amount of strength and continuity which is also available to resist progressive collapse. This has been demonstrated in the past on a number of occasions. However, since codes, standards, and building materials, as well as construction techniques change with time, it cannot be assumed that this protection will always be provided in the future. Therefore, it is considered necessary that progressive collapse provisions be included in design requirements.

J.M. Alexander: “An Approximate Analysis of the Collapse of Thin Cylindrical Shells under Axial Loading”; The Quarterly Journal of Mechanics and Applied Mathematics Volume 13, Issue 1 1960 https://academic.oup.com/qjmam/article-abstract/13/1/10/1919943

T. Wierzbicki, W. Abramowicz: “On the Crushing Mechanics of Thin-Walled Structures”; J. Appl. Mech. Dec 1983 https://asmedigitalcollection.asme.org/appliedmechanics/article-abstract/50/4a/727/390676/On-the-Crushing-Mechanics-of-Thin-Walled

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Daigoro Isobe: “Numerical Simulations for Investigation On True Cause of the Total Collapse of the WTC Towers”; International Symposium on Structures under Earthquake, Impact, and Blast Loading. Osaka, Japan October 10-11, 2008 https://www.kz.tsukuba.ac.jp/%7Eisobe/187.pdf

> It is possible that the highly-rapid total collapse of the WTC towers was caused not only by the buckling and strength reduction of members due to elevated temperatures, but by the original weakness of the member joints and the destruction of those during the collision of the aircraft.

Daigoro Isobe, Le Thi Thai Thanh, Zion Sasaki: “Numerical Simulations on the Collapse Behaviors of High-Rise Towers”; International Journal of Protective Structures Vol 3 · Number 1 2012 https://web.archive.org/web/20160116144044/http://www.us-jpri.org/en/reports/tsukuba_20150930.pdf

> In general, the tower remained standing for a longer period of time due to the catenary action of the outrigger truss system only if the load paths in the tower were protected and if the member connections were strong enough. However, in these analyses, the collapse speed never reached a value as high as that of the free fall observed in the WTC collapse, which occurred while the splices between column sections still retained their tensile strength. From these results, it is evident that the high-speed collapse of the WTC towers might have been caused by an inherent weakness in their member connections in addition to the destruction directly caused by the aircraft impact.

Nada Elkady, Levingshan Augusthus Nelson, Laurence Weekes, Nirvan Makoond, Manuel Buitrago: “Progressive collapse: Past, present, future and beyond”; Structures Volume 62 April 2024 https://www.sciencedirect.com/science/article/pii/S2352012424002832

Foad Kiakojouri, Valerio De Biagi, Bernardino Chiaia, Mohammad Reza Sheidaii: “Progressive collapse of framed building structures: Current knowledge and future prospects”; Engineering Structures Vol 206 March 1, 2020
https://www.sciencedirect.com/science/article/abs/pii/S0141029619322576

Li Shan, Floriana Petrone, Sashi Kunnath: “Robustness of RC buildings to progressive collapse: Influence of building height”; Engineering Structures Vol 183 March 15, 2019
https://www.sciencedirect.com/science/article/abs/pii/S0141029618327895?fr=RR-2&ref=pdf_download&rr=9c113249dfc54da8

> Comparison of progressive collapse in buildings of different heights, with initial column removal beginning at the corner and at the lowest floor, shows that taller buildings possess greater resilience to progressive collapse than buildings with fewer stories and same arrangement of vertical elements in the plan. […] In conclusion, for the specific study here presented, in all buildings the collapse has a distinct local character, involving the horizontal elements directly connected to the area where columns are removed, and is controlled by fracture of the reinforcing steel. Overall, findings from the study suggest that, although taller buildings possess more robustness than shorter buildings because of their inherent redundancy, it cannot be extrapolated that collapse resistance will continue to be enhanced with even taller buildings.

Floriana Petrone, Li Shan, Sashi Kunnath: “Assessment of Building Robustness against Disproportionate Collapse”; Struct. Eng. 2020 https://www.researchgate.net/profile/Floriana-Petrone/publication/345347816_Assessment_of_Building_Robustness_against_Disproportionate_Collapse/links/5fa48631299bf10f732892b7/Assessment-of-Building-Robustness-against-Disproportionate-Collapse.pdf

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Phillip J. Georgakopoulos: “An Overview of Progressive Collapse in Structural Systems”: May 6, 2005 https://dspace.mit.edu/bitstream/handle/1721.1/31117/61146362-MIT.pdf

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Serkan Sagiroglu: “Analytical and Experimental Evaluation of Progressive Collapse Resistance of Reinforced Concrete Structures”; August 2012
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Faber, Michael H.; Kübler, Oliver; Fontana, Mario; Knobloch, Markus: “Failure consequences and reliability acceptance criteria for exceptional building structures – A Study taking Basis in the

Failure of the World Trade Center Twin Towers”; Institute of Structural Engineering, Swiss Federal Institute of Technology July 2004 https://doi.org/https://doi.org/10.3929/ethz-a-004807495

Guo-Qiang Li, Jing-Zhou Zhang, Liu-Lian Li, Bin-Hui Jiang, Tao-Chun Yang and Jian Jiang: “Progressive Collapse Resistance of Steel Framed Buildings under Extreme Events”; Advanced Steel Construction – Vol. 17 No. 3 March 13, 2021
https://ascjournal.com/down/vol17no3/Vol17no3_10.pdf

> A systematic methodology based on both Monte Carlo simulation and probability density evolution method should be developed to generate a robust and sufficient large dataset for training and testing.

Jian Jiang, Qijie Zhang, Liulian Li, Wei Chen, Jihong Ye, Guo-Qiang Li: “Review on Quantitative Measures of Robustness for Building Structures Against Disproportionate Collapse”; International Journal of High-Rise Buildings Vol 9, No 2, June 2020
https://global.ctbuh.org/resources/papers/4330-02.127~154(%E1%84%8C%E1%85%B5%E1%84%8F%E1%85%B2%E1%84%85%E1%85%B5).pdf

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Liang Zong, Wanquan Fang, Yichi Zhang, Jian Cui: “Progressive collapse analysis on modular steel construction based on a simplified joint model”; Thin-Walled Structures Vol 198 May 2024
https://www.sciencedirect.com/science/article/abs/pii/S0263823124001769

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