Paper No. 2003. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

ARCHITECTURAL ASPECTS OF SEISMIC RESISTANT DESIGN

CHRISTOPHER ARNOLD, FAIA, RIBA

Building Systems Development Inc, PO Box 51950, Palo Alto , California, 94303, USA

ABSTRACT

The influence of architectural configuration on seismic performance; the determinants of configuration and the force of the need for image: architect/engineer interaction and future trends in architectural style in relation to seismic design

KEYWORDS

architecture, configuration, International Style, post-modern, image, zeitgeist

INTRODUCTION

The architectural aspects of earthquake resistant design are something of a paradox: to the engineer, the building architecture, over which the engineer generally feels he or she has little control, has major influence on seismic performance. On the other hand the architect, who has almost complete control over those aspects that influence seismic performance, often appears to have limited interest or understanding of the impact of design decisions. In extreme terms one party has great interest but no control: the other party has control but no interest. Common wisdom decrees that this situation is resolved in two ways: one, by trying to ensure understanding and communication between the architect and engineer such that engineering concerns do, in fact, influence the architect's design, and two, trying to persuade the architect to become interested and knowledgeable about seismic design issues, so that they are automatically considered as the architect begins conceptualizing the design.

These two approaches, trying to improve architect/engineer interaction, and trying to improve the architect's knowledge, take place against a changing background of design "zeitgeist", defined as the taste or outlook characteristic of a period or generation. This zeitgeist is of extreme power in shaping architectural design, and the really great architects are those who break away from the prevailing norm and produce designs of such power and conviction (to other architects, not the public) that the prevailing prototypical way of designing - or the prevailing style - begins to change.

This paper, then, will consider various aspects of the concerns outlined above:

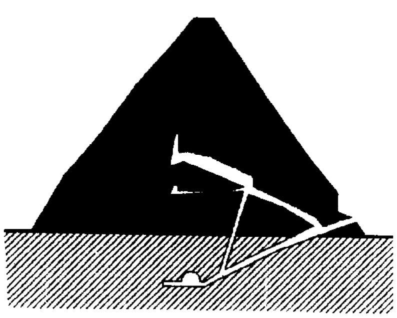
- Prevailing wisdom on architectural influences on seismic performance.
- Ideal architect/engineer interaction and the barriers to achieving it.
- Educating the architect in seismic design
- The force and nature of the International Style
- New architectural trends in relation to seismic concerns.

PREVAILING WISDOM: THE OPTIMAL SEISMIC DESIGN

Prevailing wisdom on the effect of architecture on seismic performance can best be summarized by showing a design for optimum seismic performance, explaining its characteristics and relating this to deviations from this design which progressively detract from its seismic capabilities. In doing this, a familiar list of configuration irregularities will be developed, and some of these will be discussed from an engineering and architectural viewpoint.

Architecture implies occupancy: thus a solid block of concrete, which might be an optimum seismic design, is sculpture, not architecture. The great pyramid of Gizeh is architecture, and certainly approaches an optimum seismic design, but architecturally it is very uneconomic in its use of space and volume in housing only two small rooms within an enormous volume of unreinforced masonry (Fig.1). Our optimal seismic design is compromised by the need also to be reasonably optimal architecturally -that is, in its ability to be a functional and economically viable architectural concept.

Our design shows the three basic ways of achieving seismic resistance, and these are also part of the optimization, so the building is seismically optimized architecturally, in its configuration, and also demonstrates the best arrangement of its seismic resisting elements, in complete harmony with the architecture Fig. 2). For convenience, the building is arbitrarily shown as three stories: a one story building might be better seismically, all other things being equal, but with a multi-story building we can show some necessary attributes of such a building. Considered purely as architecture this little building is quite acceptable, and would be simple and economical to construct. Depending on its exterior treatment - its materials, and the care and refinement with which they are disposed- it could range from a very economical functional building to an elegant architectural jewel; it is not complete, architecturally, of course, because stairs, elevators etc. must be added, and the building is not spatially interesting , although its interior could be configured with nonstructural components to provide almost any quality of room that was desired with the exception of interesting and/or unusual spatial volumes more than one story in height.



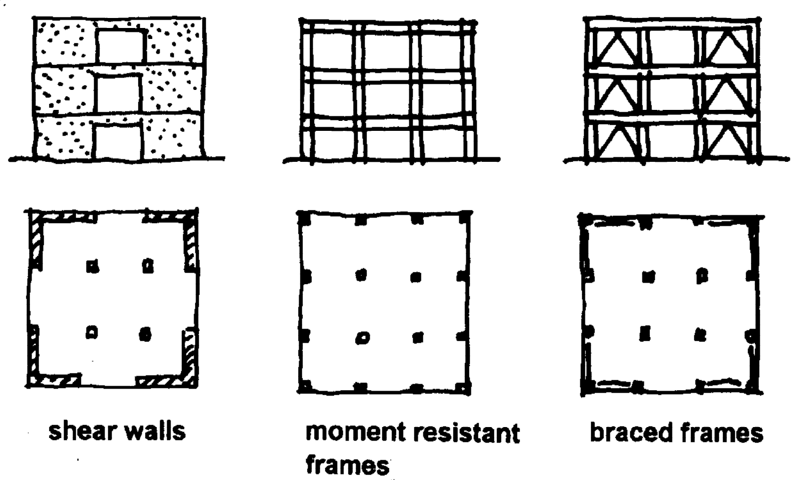


Fig.1 The Great Pyramid at Gizeh   Fig.2 The Optimal Seismic Design

What are the characteristics of this design that make it so good -considering only architectural configuration and the disposition of the seismic resisting elements? Any engineer will recognize them, but it is worth while listing them, because they are specific attributes whose existence or absence thereof can be quickly ascertained in any actual design. These attributes, and their effects, are:

• Low height-to base ratio	Minimizes tendency to overturn
• Equal floor heights	Equalizes column/wall stiffness
• Symmetrical plan shape	Reduces torsion
• Identical resistance on both axes	Balanced resistance in all directions
• Uniform section and elevations	Eliminates stress concentrations
• Maximum torsional resistance	Seismic resisting elements at perimeter

- Short spans — Low unit stress in members
- Redundancy — Toleration of failure of some members
- Direct load paths, no cantilevers — No stress concentrations

CONFIGURATION PROBLEMS

The detrimental architectural effects that engineers complain about result from deviations from this list of attributes: that is, the introduction by the architect of one more "irregularities" of configuration. Thus instead of a symmetrical plan shape the building will have the form of an L, or a T and thus introduce reentrant corners that tend both to create a torsional response and cause stress concentrations at the hinge line. Like all irregularities these may exist geometrically, but be trivial or be of major significance: the difference is due to geometrical proportion and size.

Similarly, in the vertical plane, the characteristic of equal floor heights may be compromised by introducing a very high first floor which tends to produce a severe stress concentration at the second floor column/beam connections, which often leads to disaster. This is the familiar soft story - when it is a discrepancy of relative stiffness -or the weak story condition when changes in column characteristics create an abrupt change of strength This latter condition has been the cause of many serious building failures (Fig 3).

Fig.3 Soft first story failures: Kobe, Japan, 1995

Rather than catalog a list of configuration irregularities we can refer to one listing, which occurs in the Commentary to the Lateral Force Requirements (SEAOC, 1994). A graphic interpretation of this list will be found in Arnold and Reitherman (1982). This list, which first appeared in 1975, shows all the irregularities which need special care, and the Uniform Building Code, in 1973, stated that for "structures having irregular shapes or framing systems... the distribution of the lateral forces shall be determined considering the dynamic characteristics of the structure".

The precise language here is important: the code says not that dynamic analysis must be used (rather than the simpler Equivalent Lateral Force method) but that dynamic characteristics must be *considered* - an act of judgment and experience by the structural engineer.

Subsequently, in 1988, the Uniform Building Code went further: two sets of vertical and horizontal irregularities were described in the code itself, and explicit requirements introduced that required modal analysis for designs where these irregularities occurred. Moreover the irregularities were defined dimensionally, rather than being left to the judgment of the engineer (Fig.4). This change in the code was introduced because of concerns that because consideration of configurational characteristics was being left to judgment they were, in fact, being considered inadequately or not at all.

For a full discussion of configuration irregularities, and examples of configuration-induced damage the reader is referred to Arnold and Reitherman (1982) and the Chapter on Architectural Considerations by Arnold in Naeim (1989).

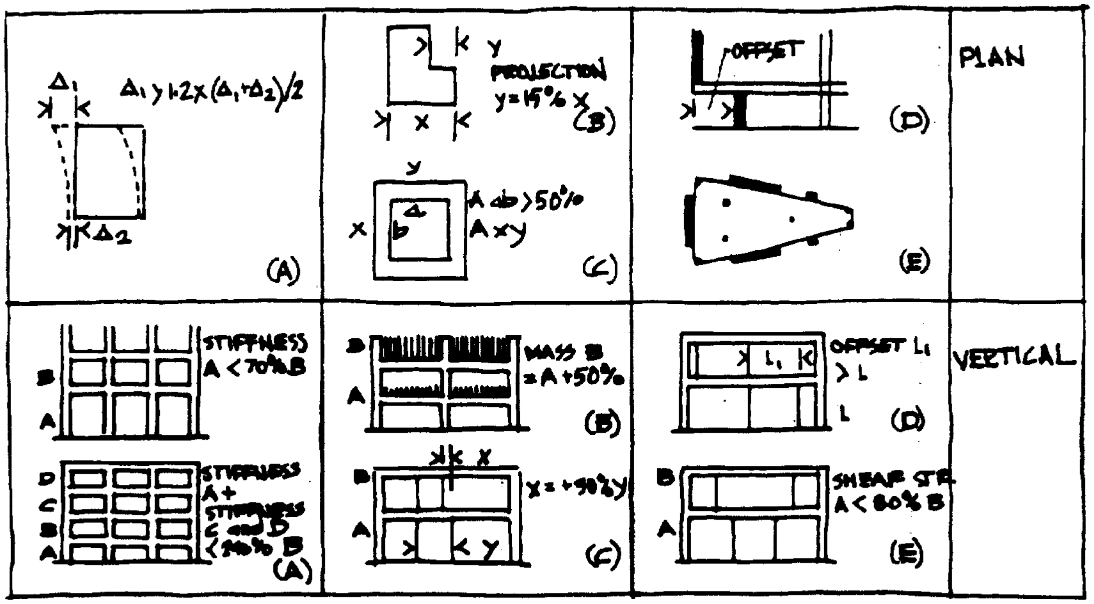


Figure 4 Configuration Irregularities, Uniform Building Code, 1988

The engineering argument on the configuration issue, in its extreme form, is that:

- Irregular configurations increase the difficulty and cost of seismic engineering and often lead to building damage and sometimes collapse.
- Configuration is controlled by the architect.
- The architect introduces irregular configurations out of ignorance or sheer willfulness, and assumes that the engineer can take care of them.
- Most of the irregularities contribute nothing to the architecture, but make difficulties for the seismic design
- If we could improve the architect's understanding he would not introduce these irregularities, or
- If he understands the problems but is willfully ignoring them then the seismic codes must force him to obey.

THE ARCHITECT/ENGINEER RELATIONSHIP

In the United States the architect/engineer relationship is further stressed because typically the engineer is employed by the architect, and if he complains too much about the architect's design he may be replaced. There are, of course, many instances where architects and engineers have built up close relationships and communicate fruitfully, with the engineer participating at an early stage of design.

However, even in these instances the pressure of business often means that , for financial reasons, the engineer is not employed until the building schematic design is complete. This applies particularly to private work, where the developer must have a design- perhaps only a three dimensional sketch -in order to procure financing, and he does not want to incur additional consultant costs until the financing is secured. The following description is of the preliminary design process of a large U.S. architectural for a client in the Pacific Rim: ".. we developed a method whereby we would send a team of three people for a week, working in the client's office, or from a hotel room, but having client input into daily charettes, lots of alternatives in sketch form, not spending many hours of presentation, but spending the hours on design. At the end of the week we would generally have a viable concept that the client had signed off." (Fuller, 1996). Thus the schematic design for a multi-million dollar project is completed in a week: presumably the design is then brought to the engineer for him to insert a structure.

Obviously, in this instance, much depends on the knowledge and experience of this three person team to ensure that the design is structurally reasonable. More risky is when analogous processes are conducted by a single architect with a desire to produce a design that will amaze his client.

In seeking improved architect/engineer interaction a number of conditions must apply:

- The engineer must communicate directly with the architectural design person or team
- The architect must take seriously his shared responsibility with the engineer for the seismic performance of the building. Recent experiences, such as Northridge and Kobe, should encourage this attitude.
- Mutual respect and cooperation: an adversarial relationship will not be productive.
- Common language and understanding:

  The architect must have some understanding of seismic engineering terms -such as acceleration, amplification, base shear, brittle failure, damping (and so on through the engineering glossary). At the same time the architect should have a general understanding of the characteristics of typical seismic structural concepts: shear walls, bracing, moment frames, diaphragms, base-isolation etc. The new concepts of performance -based sesimc design should also be understood. In turn the engineer must understand the architect's functional needs and aspirations.
- Collaboration must occur at the onset of a project: before architectural concepts are developed or very early on in their conception
- Business conditions that restrict early architect/engineering interaction must be alleviated (by the use of a general consulting retainer fee, for example, recovered from those projects that are achieved).
- If the architect does not want to interact with his engineer, or if for some reason is prevented from doing so, then he should work with simple regular forms, close to the optimal seismic design

Behind the common engineers' complaints about architects lies the engineer's belief: our optimal building design is simple and satisfactory, and can make a very nice building: why does the architect feel the need to deviate from it, and deviate in such irrational ways? Let us look at this issue: first, why does the architect deviate, and how rational are his variations?

DETERMINANTS OF CONFIGURATION

Not all architecture has the same agenda. The architect Robert Venturi distinguished between "ducks" and "decorated sheds" (Jencks, 1991). Ducks are buildings in the shape of their function, or a modern building in which the construction , structure and volume become the architecture, while the "decorated shed" is a simple building with signs attached like billboards that proclaim its function. Pursuing this a little further, we can distinguish three basic types of architecture by their general form:

- Economical containers -the "decorated shed": warehouses, industrial plants, department stores, some commercial buildings
- Problem/solving, functional - hospitals, educational, laboratories, residential,
- Image and prestige - corporate headquarters, some public buildings and university buildings, museums, entertainment.

These categories also bear some relationship to the architects, or firms, that design them, for there is much covert specialization in architecture. This causes client confusion: when the client who wants an economical container goes to a prestige architect, or when the client with a difficult planning problem goes to the container architect. In architecture, there are brain surgeons, internists, and general practitioners.

The building configuration, or concept, is influenced by three main factors:

- urban design, business and real estate issues.
- planning and functional concerns.
- the need for image.

Urban design involves issues such as zoning and planning regulations, which by defining set-backs, height limits and sun-angle requirements often define the building envelope. More recent regulations sometimes mandate aesthetic requirements , such as vertical set-backs and pitched roofs. While the form of the early "skyscraper" or large office block, has been a traditional field for architectural historians, emphasizing the technological origins of such forms, recent studies have argued convincingly that skyscraper form was predominantly determined by local land-use patterns, municipal codes and zoning (Fig. 5). For example, the striking differences in form between the skyscrapers of Chicago and New York were due to the imposition of a 130 feet height limit on the former, and no limits on the latter. Zoning laws in New York, in 1916, spawned the buildings with "wedding-cake" setbacks, while a 1923 law in Chicago permitted a tower to rise above the old height limit, but restricted its total volume (Willis,1995).

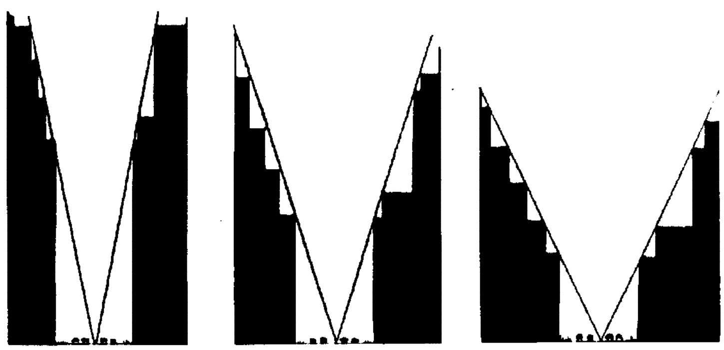


Figure 5. Set-back regulations, New York

Much of the architect's design skill and time is occupied in planning: determining the three dimensional arrangement of public and private spaces, or rooms, that will best serve his clients needs. Building planning varies enormously: while planning a church is relatively simple, the planning of a hospital is extremely complicated. Some of the tasks in hospital planning involve arranging an economical layout for nursing floors so that patient rooms can be effectively monitored by the nursing staff: this is one of the key design problems in hospital planning, and specialist hospital architectural firms each develop their own ways of solving the problem. But the nursing floors must be related to treatment areas such as radiology and operating procedures: out patients must be accommodated, an extensive materials supply and distribution system be devised, laboratory functions often dealing with toxic substances accommodated, discreet access to the morgue arranged, and administration and office functions made convenient. Each of these major planning areas breaks down into a myriad of detailed planning tasks, and to each area the correct environment controls- air quality, lighting, and acoustics - must be available, and a number of utility services be led. Often, the whole complex must sit atop a multi-floor parking structure.

It is unlikely that our simple cubical building will be able to accommodate all the needs of a hospital: other building types -hotels and apartment houses , offices and institutions, schools and universities, churches and stadiums - all have their functional demands that impact the form of the building. Nevertheless, it can be argued that however complicated the planning requirements of the building, they can be met by combinations of relatively simple building "blocks", sized and configured to meet the needs of the particular function. This can work well for very large complexes, but the real problems occur in the medium to large buildings with difficult functional requirements in which breaking the building up into simple rectangular blocks is not feasible, because of space or other restrictions - such as the need to make pedestrian movement quick and convenient.

THE NEED FOR IMAGE

Engineers can accept the problems of zoning and building function in determining configuration, because they fit into the engineer's rationalist concept of the world: that while their world may be conditioned by the laws of physics the architect's world is impacted by planning regulations, real estate economics and functional planning requirements. It is the third influence, the need for the building to present an attractive, interesting, unique, or even sensational image to the outside observer, and often the occupants, that engineers feel the trouble begins. Here is where the irrational artist takes over, and the laws of physics are violated.

It is important to understand the need for the architect to provide a distinctive image for the building. It is recognized that this is not always the case. Often the need is for a simple, well-mannered, unobtrusive building, that will satisfy the local planning department and look nice to the owner, but not exceptional. The kind of problems that engineers complain about, however, generally occur when the owner and architect are trying for something more: at least a building that will stand out from its neighbors and present a commanding image , and at most, a major artistic masterpiece. It is because of the need for an image that owners go to the architect - and often to a specific architect famed for his ability to provide an image - in the first place. If this need did not exist the owner might go to an engineer -or contractor- to obtain our optimal simple building.

The needs for imagery in buildings are complex: some of them may have to do with marketing a commercial name or product, or the name of the owner. Some owners like to purchase an architect's design in the same way as they purchase any other work of art. Their desire may be shallow, and based on fashion, or may be based on a deep understanding of and love for architecture and the desire to be a patron. Be that as it may, the architect's ability to provide images is of great importance, and the architect's education, in the United States, is still is very strongly biased towards the investigation of aesthetic form in the design studio as against the study of technical subjects such as materials, utility systems and engineering. (This bias is controversial and a constant source of discussion in United States architectural circles).

All architects, in theory, strive for the perfect merging of aesthetic form with efficient function. (Read the brochure of any architectural firm to ascertain the truth of this observation). This occurs at all levels of design, and of course the architect's aspirations and resources are more limited in the design of a warehouse than of a corporate headquarters. The functional planning of a hospital will generally take precedence over the pursuit of pure form, though even here the architect will try and provide an image building that fits its surroundings and is attractive to occupants and visitors.

The pursuit of image means that in architectural design there are strong aesthetic and cultural objectives that are very seldom present in works of pure engineering (though bridges, in particular, can achieve very high aesthetic quality). In pursuing image the architect expresses his idea of an aesthetically satisfying building but he does so within the zeitgeist (unless he is a rebel or a genius). Up until the early years of the 20th. century for a Western architect the zeitgeist dictated a historical style -typically mediaeval or renaissance, even when totally new building types such as railroad stations or skyscrapers were conceived. In engineering and materials terms the forms were all derived from masonry structure: the need to keep the blocks of masonry in compression, and the devising of clever means, like arches and vaults, to enable the compressive masonry material to achieve larger spans than were possible by using slabs of masonry as beams or lintels. These masonry devised forms survived well into the 20th. century, even when buildings were supported by concealed steel frames, and arches had become an anachronism.

THE INTERNATIONAL STYLE

The revolution in architectural aesthetics that, for convenience, we will call the "International Style" had many dimensions, aesthetic, technical, economic and political. For our purposes, its significance was that of revealing and enjoying the new forms, such as cantilevers, long spans, and previously unachievable delicacy and slenderness, that the (steel or concrete) frame structure had made possible, but which had not been exploited because of the strength of the existing historical zeitgeist. The International Style was not alone in enjoying new forms and extoling the virtues of unadorned structure and absence of decoration: a glorification of the beauties of Euclidean geometry. The same thing was going on in the world of painting and sculpture, and these arts were being stripped of their traditional content in favor of simplicity, geometry, and new materials. In painting, the naturalist painter Mondrian gradually stripped his painting down to a few primary colored orthogonally arranged lines, and produced works of such force that they are recognized by his name to this day all over the world. The Russian constructivist artist Malevich painted an off-white square against a white background. The sculptor Brancusi produced near abstract forms of stainless steel, midway between a sculpture and an industrial object. So the International Style in architecture was completely within the (advanced) culture of the times.

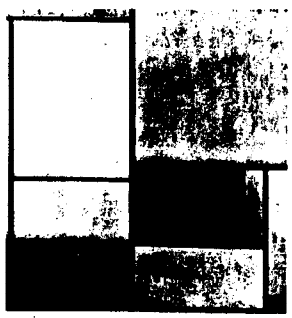


Figure 6 Mondrian

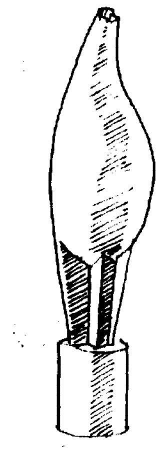


Figure 7 Brancusi

As architects began to exploit what the engineers had given them the seeds of seismic configuration problem were sown. Load-bearing masonry buildings were very limited in the extent to which configuration irregularities were possible: with short spans redundancy was always present: the extensive use of walls, both in exteriors and interiors, meant that, even though the masonry was unreinforced, unit stresses were very low. Large cantilevers were not possible. Moreover, the prevailing architectural styles preferred symmetricality, and decreed that buildings should be massive at the base, with smaller openings, and their mass should decrease with the upper floors. The Italian Palazzo style of renaissance architecture dominated the design of large buildings and even influenced the early skyscrapers.

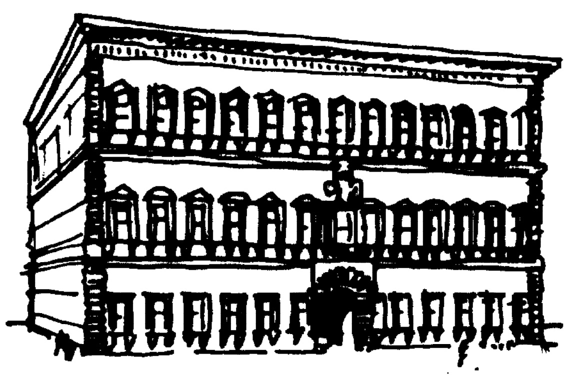


Figure 8 The Italian Palazzo form

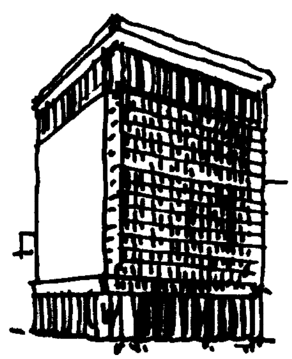


Figure 9 Early skyscraper

But with the steel or concrete frame all these limitations were unnecessary: buildings could be unbelievable slender (because now the columns and beams were analyzed and sized by engineers), first floor walls could be omitted, so that the building seemed to float in space, and the building could cantilever out safely so that it could get larger as it rose: the inverted pyramid could be built. And with these possibilities, eagerly explored by new architects, came other ideas: the rejection of symetricality in favor of a more exciting and more rational disposition of elements (rational because the building elements were allowed to occur where planning function was most efficient, instead of being forced into [sometimes] inefficient symmetry). A new morality of :"truth to materials" arose: it was essential to reveal and express the structural materials, steel, concrete or wood, and not conceal them with facing materials unless necessary for weather protection. The grammar of the new architecture was expressed by the Swiss /French architect Le Corbusier (Le Corbusier, 1929):

- The use of "pilotis" (elevating the building above the ground on columns)
- Roof-gardens (to provide greenery in the congested urban setting)
- The free plan (eliminating the need for interior load-bearing walls)
- Continuous glazing (the precursor to the curtain wall)
- The free facade (the exterior as a light nonstructural element supported by the frame)

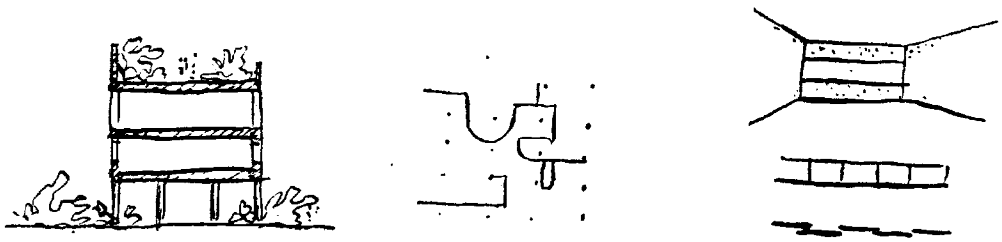


Figure 10 Le Corbusier's manifesto: the new architecture

All these elements, with the exception of the roof-garden, became familiar elements of the "vernacular" architecture of the 1950's to 1970's, using the term vernacular to signify the everyday architecture of commerce, industry and institutions. At any time there are always architects who work outside the vernacular pursuing personal objectives: the important American architect Frank Lloyd Wright, for example, never worked in the International Style.

Other aspects of the International Style and its later evolution included a new appreciation of the work of the engineer on the part of architects. The bridges of Robert Maillart, in Switzerland, were greatly admired by architects, as was the work of the architect engineer Pier Luigi Nervi, in Italy. Engineers such as Ove Arup, in England, collaborated productively with architects in enriching the vocabulary of simply expressed structure.

The fruits of Le Corbusier's 1925 manifesto (and there were many other architects preaching essentially the same message) grew with difficulty before World War 2, and then bloomed in the rich economic years that began in the 50's. The United States , Western Europe, Latin America, the Soviet Union and Japan first rebuilt their war damage then exploded in a fury of development, almost all constructed in their regional versions of the International Style. These years of explosive development saw our cities grow into huge metropolises: they were also years in which seismic design as it related to the new, spare, framed buildings was inadequately understood, and it took earthquakes in Latin America, Mexico and the United States (in Alaska, 1964, and San Fernando, 1971) to make engineers realize that such buildings were unforgiving and intolerant of the very irregularities that architects had embraced with such enthusiasm. Almost all the world-wide inventory of these inadequate buildings (1950's to mid 1970's) is still with us.

This extended historical discourse is relevant to the architecture of seismic design, because it shows that:

- the minimalist structural frame provided the basis for an architectural aesthetic which was in tune with the spirit of the age, aesthetically, economically and politically: the zeitgeist changed.
- the discontinuities, irregularities, spareness and lack of redundancy were critical symbols of the new architectural aesthetic.
- these elements were made possible by the use of the engineered structural frame, and by a new level of architect/engineer collaboration.

In other words, those features of the International Style which eventually became serious problems in seismic country emerged not as architectural aberrations in opposition to the engineers but in an atmosphere of mutual respect, interest, and understanding. It is, however, worth mentioning, that the new style originated , was promoted and worked out in Western Europe, predominantly France and Germany, which, of course, are essentially non seismic zones.

As noted above, the architecture of the 50's to the 70's has left us with a legacy of poor seismic configurations that present a serious problem in reducing to earthquake threat to our cities. The problem is exacerbated when it is allied to the engineering design problem of the use of the non-ductile reinforced concrete frame structure, which was the norm up to about 1975. After this period, understanding of the configuration problem and new codes that required ductility in reinforced concrete frame tends greatly to reduce the magnitude of the problem. However, many engineers felt that architects were not responding seriously enough to the now defined strictures on configuration: designs with major irregularities continued to be presented to engineers with the demand that they be made safe without constraining the architecture.

EDUCATING THE ARCHITECT

In fairness to architects, the historical study above shows that an engineer might be asking an experienced architects in the 80's or 90's to change the design habits of a life time which he had developed in concert with his engineering collaborator. It is no wonder,perhaps, that architects are slow to react, particularly since not all engineers are equally clear on the deficiencies of the designs with which they are confronted. In accord with the U.S architect/engineer business climate, an architect who finds his design criticized by his engineer can generally find an alternative engineer who will accommodate him. It is extremely hard to ascertain whether this second engineer reaches this accommodation because he is more ignorant than his colleague, more of a gambler, or more inventive and clever.

Parenthetically, architects in the U.S. are now being asked to reconsider the use of steel moment -resistant frames for new projects because of problems revealed in Northridge and Kobe. This is a particularly attractive structural concept for architects because of the open interior planning it allows, free of shear walls or restrictive braced frames. Only recently hailed by engineers as the optimum seismic structure, and awarded premiums of force reduction in our codes because of its excellence, the concept is now being snatched away from architects in favor of more restrictive and conservative designs.

While it is reasonable for engineers to ask that architects become better informed about seismic design and the consequences of their configuration decisions, the engineer must understand that while for them seismic design is of paramount importance, for architects it takes very low priority as far as there own interest. Seismic design and safety is taken care of by the engineer: it is no more a subject of concern than provision for vertical forces, which never comes up for discussion between owner and architect, and seldom between architect and engineer. Meanwhile, as noted above, the architect has many pressing things on his mind, which he must discuss with his client and other consultants, if he is to meet his schedule and budget - and also have a profitable job for his office.

Architects vary greatly in their interests: the stereotype of the architect as an unworldly aesthete is seldom true. Some architects are brilliant salespeople and business managers: some are very close to engineers, and interested in how the building is engineered and constructed: some are excellent project managers and will ensure that budgets and schedules are kept: some are inspiring managers of people and will run an exciting and enjoyable office: some are brilliant at the design of details, the behavior of materials and the development of construction documents: and some are thoughtful and inventive designers. The large, well-run office will have a mix of the above in its staff. The small office must try and find a few people that combine the above roles. As the profession of architecture becomes more complex, specialization is becoming more common: even large firms cannot play all roles, and the small office must specialize in a limited type of design. The advent of CAD and other information systems has extended the range for the small practitioner, but these systems need large capital investments that produce their own forms of limitation.

AFTER THE INTERNATIONAL STYLE: POST-MODERNISM

The conditions that gave rise to configuration problems in seismic design have been discussed, with emphasis on the cultural environment within which the architect works, and the importance to him of achieving an image which is not necessarily rational in seismic engineering terms. We have suggested that the architectural zeitgeist began to change about 1975: what happened, what is today's aesthetic environment and what can we say about the future?

This is not the place for an extended history of post-modernism and allied trends in recent architecture, but some discussion of these trends in relation to the seismic problem is of interest. We shall also be looking to see whether any of these trends suggest a concern for seismic design as part of their culture, for regions that are seismically active.

The tenets of the International Style began to be seriously questioned in the mid-1970's, both in print by architectural critics and historians and in practice by architects beginning to bring new design approaches to the drawing board and to construction. This questioning finally bore fruit in an architectural style know broadly as "Post-modern". Although this term was criticized by critic and the architects themselves who were seen to designing in this style, the term became a useful mark of identity. In general, post-modernism meant:

- the revival of surface decoration on buildings
- a return to symmetry in overall form
- the use of classical forms, such as arches, decorative columns, pitched roofs, in nonstructural ways, and generally in simplified variations of the original elements.
- a revival of exterior color as an element, with a palette of characteristic colors (e.g. dark green, pink, Chinese red, bright yellow, buff etc)

Developments of post-modernism also involved the revival of full, scholarly, classical revival as a style., and very personal design by a few prominent architects in terms of scale and forms, which were derived from a variety of sources, such as Victorian engineering, ancient Egyptian architecture and Euclidean geometry.

In seismic terms, this change in the Zeitgeist was, if anything, beneficial. The return to classical forms and symmetry was helpful to the structure as a whole, and almost all of the decorative elements were nonstructural. Inspection of two early icons of post-modernism, the Portland office building designed by Michael Graves (Fig. 11), and the AT&T Tower (Fig. 12), designed by Philip Johnson, show extremely simple and ordinary structures. Indeed, the Portland building, which created a sensation when completed, has a form that approximates our optimal structure: the sensation is all in the nonstructural surface treatments. The Johnson tower was remarkable only for its top, modelled like a piece of antique furniture.

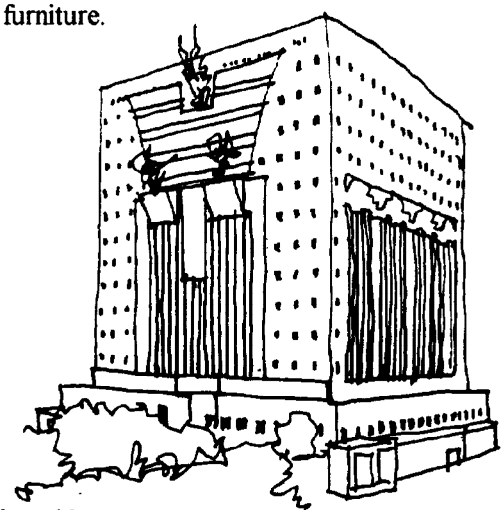


Fig. 11
Office Building, Portland, OR (1979)
Michael Graves Arch.

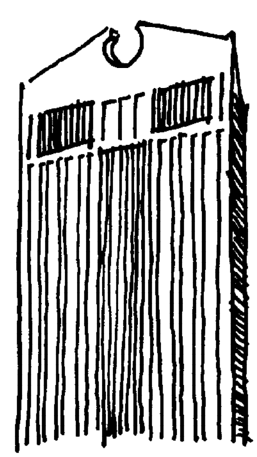


Fig. 12
Top of AT&T Building, New York (1977)
Johnson/ Burgee, Arch.

Beneath every huge quasi-classical post-modern column will be found an engineered steel or concrete member that is supporting the building. It should be noted, however, that an interest in seismic design had no influence on the development of post-modernism - it is, and was a strictly aesthetic and cultural movement. It should also be noted that the post-modern movement in architecture was accompanied by similar movements in the other arts: the rise of performance and installation arts in the art museums and a post-modern movement in literature.

At the same time that post-modernism was making historical architectural style legitimate again, another style evolved in parallel:. This style, originally christened "hi-tech" (the term has not stuck) returned to the celebration of engineering and new industrial techniques and materials as the stuff of architecture. This style developed primarily in Europe, notably in England and France, and the influence of a few seminal works, such as the Pompidou Center in Paris, the Lloyds building in London, and the Hong Kong and Shanghai bank in Hong Kong. These buildings proclaimed a new version of the functionalism of the thirties, updated to provide flexibility, adaptability and advanced servicing for an uncertain future, using exposed with beautiful castings as connections. In truth, these buildings are as aesthetically and stylistically conceived as any post-modern or classical revival building.

The rise of post-modernism released architects from the strait-jacketed moralities of the International Style. As a result, at present a kind of aesthetic bedlam reigns, and several competing zeitgeists co-exist, competing for clients - and finding them. The leading exponents of the new styles form an architectural jet-set, cruising the world dropping of their stylistic gems to clients and countries that can afford them. The leading American architects work in Japan and along the Pacific Rim and their Japanese peers work in the U.S. The British masters of hi-tech work in Japan and the rest of Europe, and the grand projects in Paris, sponsored by the late President Mitterand, provide a dazzling display of advanced styles.

AN EARTHQUAKE ARCHITECTURE

In the search for meaning in architecture beyond the superficialities of fashion one might expect that the seismic regions of the world would develop an "earthquake architecture". Such an architecture might expose the elements necessary to provide seismic resistance in ways that would be of aesthetic interest and have meaning beyond mere decoration. With a few exceptions this has not happened. The half-timbered structures of mediaeval Germany and England are early examples of exposed structure, including bracing against wind. Church architecture in Mexico developed a style known as "earthquake baroque" in the seismic region of Oaxaca, where the proportions of the vaults a much squatter than in other parts of Mexico, to create a more resistant building.

In modern times lateral bracing is sometimes exposed, to create its own decorative pattern (Fig. 13). The absence of enthusiasm for an "earthquake architecture" may be due to the psychological desire to deny the prevalence of earthquakes: building designs which remind the knowledgeable observer are striking a negative note. A recent interesting example of earthquake architecture by one of the most cerebral of New York architects is the Nunotani Office Building in Tokyo (Fig. 14). The architect, Peter Eisenman, says that the building represents a metaphor for the waves of movement as earthquakes periodically compress and expand the plate structure of the region.

NEW ZEITGEISTS

The importance of well-publicised designs by fashionable architects is that they create a new zeitgeist. Architects are very responsive to form and designs and once a form gains credence practicing architects the world over begin to reproduce it. Today's New York corporate headquarters high-rise becomes tomorrow's suburban Savings and Loan Office. This phenomenon became clear in the adoption of the metal and glass curtain for building exteriors. The first two highly publicized curtain walls were that of the United Nations building and the Lever Brothers building, both in New York city in the early 50's: by the mid 60's every town in America had its stock of blue-green glazed commercial buildings. So, to predict the design vernacular of the future it is necessary to look at what is being done in high-style architecture, and in particular, which forms look as if they are catching the imagination of architects and starting to be reproduced at a more modest level . Again, we are looking at these to see if they may provide clues for the future of seismic design and the architect/engineer relationship Amid the bedlam of design voices, we will briefly discuss three trends.

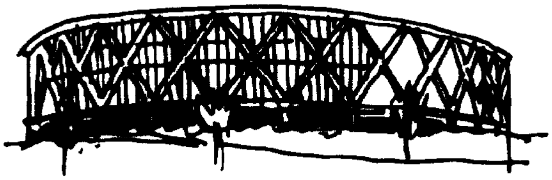


Fig.13 Oakland-Alameda County Stadium, Skidmore, Owings and Merrill Arch .

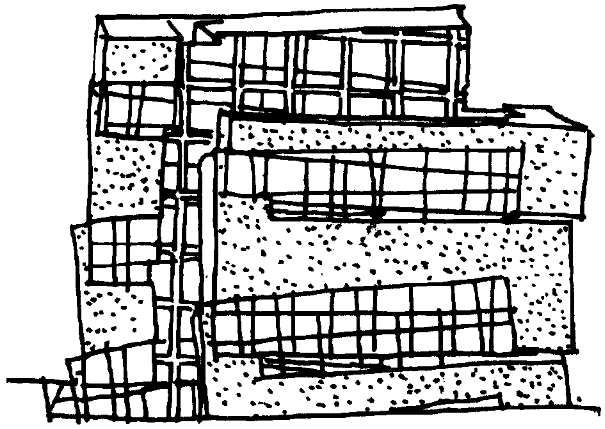


Fig. 14 Nunotani Headquarters Building,(1991) Edogawa-ku, Tokyo, Japan Peter Eisenman Arch.

<u>The bridge building:</u>

The bridge building form is that of twin high-rise buildings connected at the roof with horizontal occupied space that acts a a bridge. The concept is that of a single building. The prototypical form of this, that seized architect's imaginations, is that of the Grand Arche of the Defense (Fig.15), in Paris, one of the late President Mitterand's "grand projets". This is a single office building, some 34 stories tall, designed as a cubical arch, framing the end of the Defense development on the perimeter of Paris. The arch is in line with the main axis through Paris to the Louvre, on which lies the Arch De Triomphe. The horizontal bridge structure provides exhibition and meeting spaces.

A similar form is that of the Umeda Sky Building (Fig. 16) in Osaka Japan. This building incorporates a mid-air garden , midair escalators and a mid-air bridge to connect the two parts of the building. The architect, Hiroshi Hara, sees this form as the beginning of an approach to a three-dimensional network to our congested cities. This building is in a fairly severe seismic zone and is carefully designed for earthquake resistance.

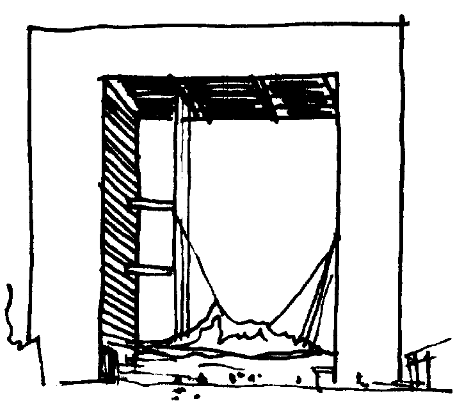


Fig. 15 Grand Arche of the Defense, Paris Johan Otto von Spreckelsen, Arch.

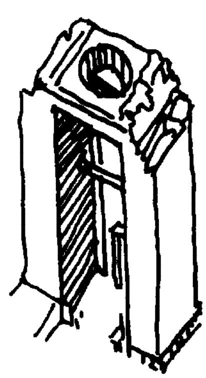


Fig. 16 Umeda Sky Building, Osaka Japan (1988) Hiroshi Hara, Arch.

Another building of similar form has recently been completed in Hawaii. A variation of the form is that of twin towers connected by a bridge: several buildings of this form have been built or projected: the Petronas Twin Towers under construction in Kuala Lumpur, Malaysia will be the tallest building in the world when completed. The bridge or twin tower forms have immense drama and appeal, and so we can expect to see five story versions of them appearing in our shopping malls and suburban centers.

<u>The warped building:</u>

A strong design trend is that of buildings that use warped forms, often combined with non vertical walls and irregular warped exterior surfaces. The most prominent exponent of these forms is the American architect Frank Gehry, who is now building these forms all over the world. His American Center in Paris (Fig. 17) is typical of his style. A surprising fact about this building is that its configuration was strongly determined by a local planning requirement that one corner of the building, which faced a park, be sliced off at a 45 degree angle. Gehry made this corner the main entrance: the result is a striking example of how a really creative architect deals with a planning limitation. His tower for the Rapid Transport Headquarters in Los Angeles (Fig. 18) shows his warped and non vertical forms applied to a skyscraper. To those who find this form irrational, a reminder of the form of a tree may provide relief. Despite its flourishes, the building is essentially rectilinear which allows for a conventional high-rise frame with structural deviations applied locally.

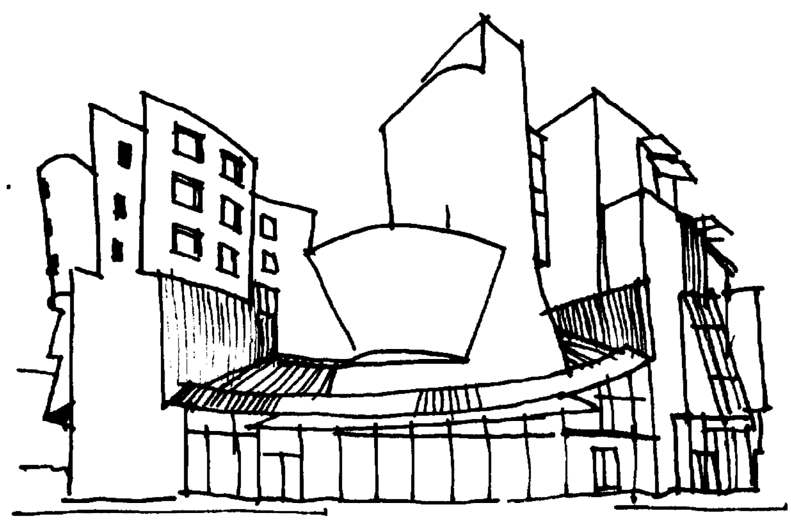


Fig. 17 American Center, Paris , France
Frank Gehry, Arch.

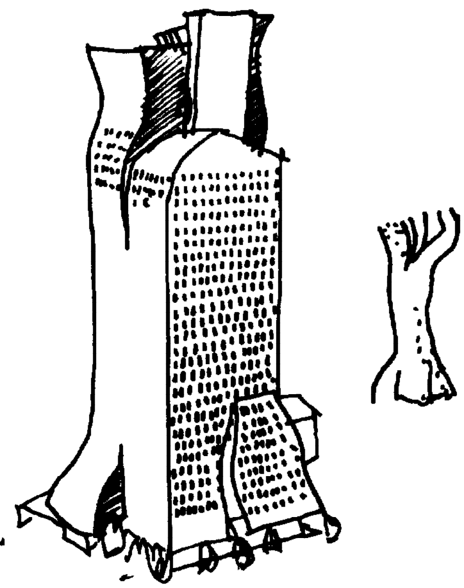
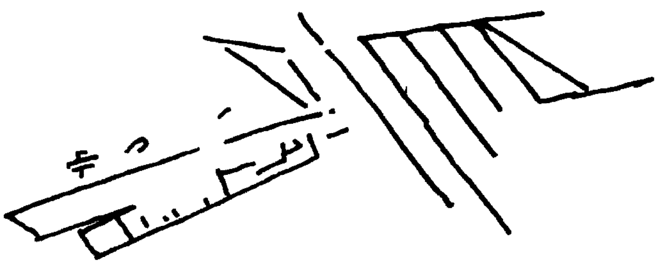


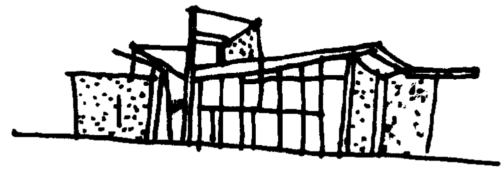
Fig. 18 Rapid Transport District Headquarters.
Los Angeles , Frank Gehry, Arch.

<u>Deconstruction</u>

Deconstruction is a term applied to a number of architects presently working around the world: the term is derived from the language and literary movement of the same name that literary criticism. The principles of deconstruction were first formulated by the French philosopher and critic Jacques Derrida, in the early 1970's and have since revolutionized literary criticism and the study of language and meaning. One of Derrida's techniques is to "take language apart by reversing the order of ideas and displacing, and thus transforming each of the terms - perhaps putting them in slightly different positions within a word group....or by substituting words in other languages that look and sound alike " (Grolier.1993). One of the architects most commonly associated with deconstruction is the Iraqi, Zaha Hadid, who works in London. Figure 19 shows her design for a prosaic building - a fire station completed in 1993 in Germany.



Plan



Elevation

Fig. 19 Fire Station, Vitra Factory Complex, Weil-am-Rhein, Germany, Zaha Hadid , Arch.

CONCLUSIONS

These examples of new trends in architecture have been selected because experience has shown the force of images created by architectural innovators, however strange they may at first appear. The architects illustrated are those -among many- who are having great influence in the schools of architecture and among younger professionals. Engineers may expect to be confronted by these kinds of configurations in the coming years.

Engineering rationality, and even buildability, appears to have little influence on these forms. There is controversy in the profession about this, and many critics view the new architecture as akin to theater set design, in which image is everything and its method of construction and longevity is irrelevant. Be that as it may, the zeitgeist is changing, and architects will perforce have to obey it. Successful engineers will understand these imperatives, enjoy the experimentation that this work represents, and assist the architects in realizing their ambitions. New methods of analysis will help, but engineers must also continue to develop their own innate feeling for how buildings perform, and be able to visualize the interaction of configuration elements that are quite unfamiliar.

Meanwhile, the residue of configuration problems left by the architecture/engineering of the 50's to 70's must be dealt with. Some will disappear as ageing buildings are replaced: this should be encouraged, as it is the only guaranteed way of removing the earthquake threat. For other buildings, engineers must use their ingenuity and imagination to find affordable methods of retrofit. And there need be no recriminations: these problems are the joint product of architect/engineer interaction that, in its time, was fruitful: nature always has the last word in reminding us of our collective ignorance.

Simple, economical buildings will continue to be built, and our optimal seismic design will continue to be viable. It may form the basis of performance based design which, if it is to be successful, will have to be free of the kinds of irregularities that make performance prediction difficult or impossible. We may expect design to develop in ways analogous to the poetry and prose of written communication. Most discourse is carried out in prose: the serviceable language of business and news reporting. At the level of literature, prose approaches an art form, in which the subtleties of language and human behavior are explored. Out in advance, often almost unintelligible, are the poets using words and language in new and unexpected ways: but over time they reveal insights in language so compelling that our speech and even our behavior is changed. Thus the language of Shakespeare shows up in the newspaper and even the office E-mail.

REFERENCES

Arnold, C and Reitherman, R.K.(1982), *Building Configuration and Seismic Design*, John Wiley and Sons, New York

Fuller, L.P. (1966). Going Global. *World Architecture*, 42 , 24-25, London

Grolier Multimedia Encyclopedia (1993), Danbury CT, USA

Jencks, C. (1991) *The Language of Post-Modern Architecture,* Rizzoli, New York

Le Corbusier (1929) *Oevre Complete de 1910-1929*, Editions D'Architecture Erlenbach-Zurich

Naeim, F. ed. (1989), *The Seismic Design Handbook*, Van Nostrand Reinhold, New York

Willis, C. (1995). *Form Follows Finance,* Princeton Architectural Press, New York