DESIGN PRINCIPLES—Actually, the World Trade Center exterior will be a bearing wall-space frame system which offers high efficiency in resisting wind loads.

Each tower structure will act as a large cantilever beam having a square cross section measuring 209 feet. This can best be shown by the stress distribution due to wind diagrammatically illustrated in Figure 6a.

As the horizontal force F is applied to section A B C D acting on plane A B, tensile forces are applied to columns in this plane and compressive forces are applied to the columns in plane C D.

The exterior walls act as gigantic Vierendeel trusses formed into a square box section stiffened at each floor level by the floor system. The force F is carried to the corners where it is absorbed in planes A C and B D respectively. With wind in the direction shown, the exterior Vierendeel truss walls in planes A C and B D are designed to carry moments and shear to the foundation. The stress distribution in a row of columns for one floor section is illustrated in Figure 6b where each column portal is spaced 3 feet-3 inches on center. There are 300 columns per floor to analyze; with 110 floors there would be 33,000 columns per tower; therefore, the analysis of the columns was carried out by electronic computer.

The floor system is not designed to carry any moments due to applied horizontal forces. The structure, then, becomes a huge internally-braced cantilever box beam where, as illustrated in Figure 6a, the Vierendeel truss walls in planes A C and B D act as web members taking shear; while the walls in planes A B and C D act as flanges to absorb compressive and tensile forces.

The maximum loads on the external columns will be relatively light for a structure of this magnitude. The 3 foot-3 inch and the 9 foot-9 inch column module will carry maximum loads of 2000 and 5800 kips respectively. However, the corner core columns at the base of the structure will carry maximum gravity loads of 25,000 kips.

The foregoing simplified illustration and explanation provides some insight into the basic design concepts employed to analyze this structure. Actually, many hundreds of pages of calculations were made and many alternate methods were considered before the plans were finalized.

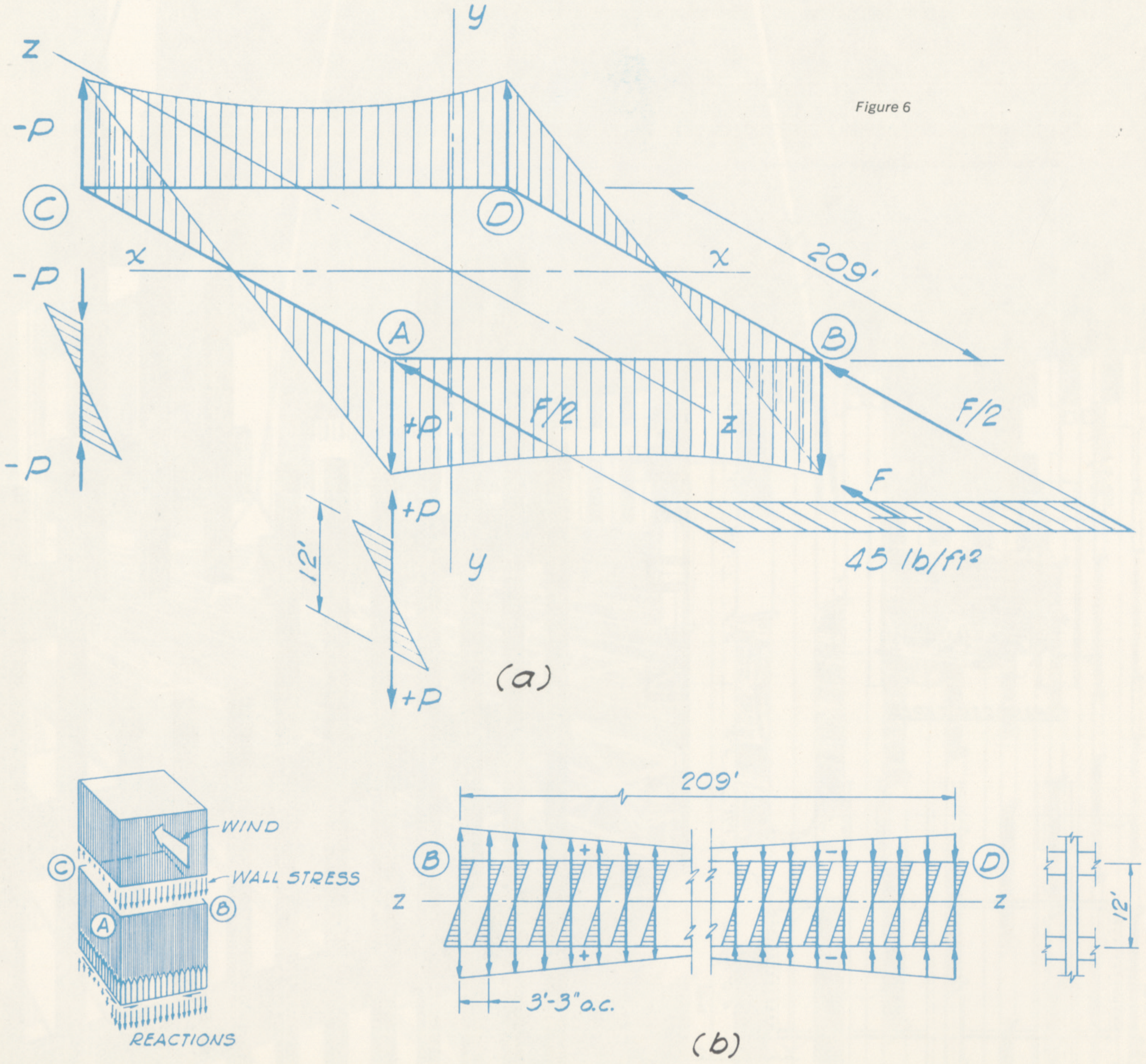

Figure 6

VARIETY OF STEELS—Another very interesting design feature in this structure is the employment of various grades of steel. All steel used in the core columns will be ASTM Designation A36. However, the steel plate to be used in the columns of the Vierendeel truss walls will include 12 different grades having yield points between 42,000 psi and 100,000 psi, with allowable working stresses as high as 45,000 psi.

Figure 7 shows the employment of high strength steels in the structure. The illustration locates the grade of steel at various levels of the structure.

The engineers made a detailed study to determine what combination of cross sectional area and grade of steel would produce the most economical and structurally sound design. The column sizes and steel grades were determined for the exterior walls of the structural system by formulae developed to produce the maximum structural efficiency and economy. The areas of the columns are proportioned to produce the same dead load unit stress in all columns at any floor. Structural columns under load shorten in an amount directly proportional to their length and unit stress. This condition was accentuated by the unusual 1400 foot long columns used in the World Trade Center structures.

The principal objective was to prevent uneven settlement throughout the structure as loads were applied. For example, columns 1400 feet long proportioned strictly on an allowable stress relationship would shorten 8 inches stressed at 15,000 psi for ASTM A36 steel. However, for heat treated low alloy steel, they would shorten 24 inches at 45,000 psi. This uneven settlement as construction proceeded would make it relatively impossible to keep the floors level. This would be a serious and costly problem to correct in a building of lesser size, let alone one of the magnitude and proportions of the World Trade Center towers. Figure 8 illustrates the uneven warpage at various stories if the columns were loaded at their working stress levels. If the core columns using only ASTM Designation A36 steel were loaded at 15,000 psi, while the exterior wall columns were loaded to their respective stress levels, there would be a floor warpage differential of 5.87 inches at the 66th floor. However, by keeping the stress levels constant at each floor the engineers have eliminated all differential settlement.

Proportioning the columns to produce the same unit stress due to gravity loads also achieved the built-in increase in safety factor mentioned earlier. The Vierendeel truss walls are utilized to distribute the stress from points of over-load to areas of strength. This reserve strength can be drawn upon should the structure suffer severe damage for any reason.

For example, an ASTM Designation A36 column at an allowable stress of 15,000 psi has a factor of safety of 1.8. A heat treated high alloy steel column stressed at 15,000 psi rather than its allowable 45,000 psi has an effective factor of safety of 5.4. Based on yield strength and assumed gravity load distribution of 80 per cent dead load and 20 per cent live load, the maximum live load increase at ultimate strength may be found as follows:

DL	LL	Reserve	
$.8P$ +	$.2P$ +	$4 \times (.2P) = 1.8P$	(For A36 steel).
$.8P$ +	$.2P$ +	$22 \times (.2P) = 5.4P$	(For heat treated steel).

This results in a 400 per cent reserve for A36 steel and 2200 per cent reserve for the heat treated alloy steels. In this case, P equals the calculated axial load in the columns.

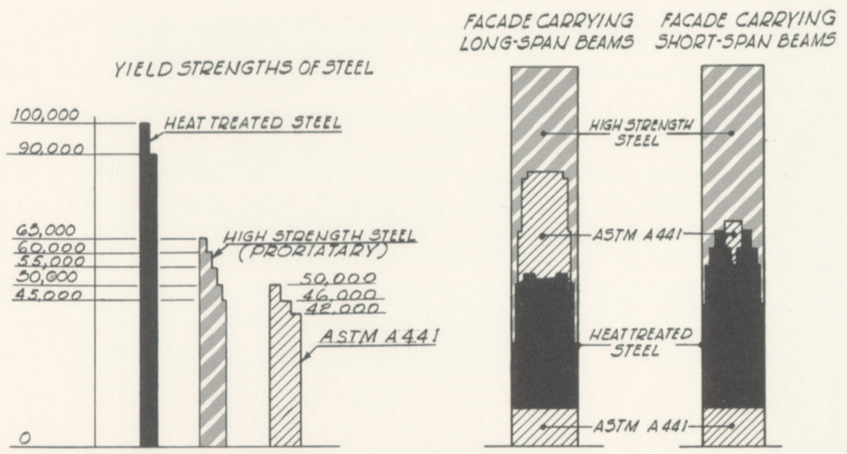

Figure 7

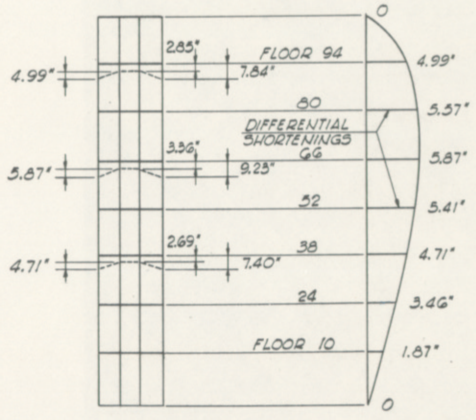

Figure 8

DESIGN APPLICABILITY—The ingenuity of the engineers in designing the World Trade Center Towers with maximum economy, safety and efficiency in planning for both shop fabrication and erection will probably result in one of the wonders of the engineering world. They took maximum advantage of the new materials made available to them by the steel industry. Likewise, they used with maximum efficiency an excellent design concept to insure stability, economy and speed of erection.

The proposed methods of erection which take advantage of prefabrication, along with the World Trade Center's design concepts, may result in an entirely new approach to designing high rise buildings. The increased rentable space made possible by long span construction, which frees occupancy areas of internal columns, cannot be overlooked by future planners.

Also, the tremendous saving in steel (40 per cent less steel than would have been used with a more conventional design) cannot be overlooked by economy-minded planners of structures of considerably lesser proportions than the World Trade Center. There is no reason why the same principles utilized to design these 110-story towers cannot be employed for buildings much lower in elevation. In buildings of less magnitude, ordinary rolled shapes or shapes fabricated of plate could probably be used.

Rolled shapes and plates having yield points between 36,000 psi and 50,000 psi and respective working stresses between 22,000 psi and 33,000 psi are readily available to ASTM Specifications. Likewise, many proprietary rolled shapes and plates are available with yield points of 45,000, 50,000, 55,000, 60,000 and 65,000 psi.

Today, the engineer designing steel buildings has the materials and tools to create structures that were considered impossible even in the recent past. The revised specification and new structural materials provide him with passport and ticket to a new world of structural design—a world to be explored as the engineers of the World Trade Center have, with careful efficiency and bold imagination.