MEGA HIGH RISE ELEVATORING

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ABSTRACT

This paper will review and categorize the passenger elevatoring designs for the current list of world's 10 tallest buildings. It will discuss the latest methods for elevatoring some of today's planned mega high rise buildings and multi-use complexes, including the use of sky lobby shuttles, top up and top down locals and double deck applications. Finally, we will explore the development of new ACV^{3}F pulse width modulation and synchronous permanent magnet motor technologies that will permit roped elevator duties of 1800kg at 15 m.p.s. single decks or 2250/2250kg at 10 m.p.s. double decks. In the future, these hoist machine applications might be expanded to permit the use of triple or even quadruple deck sky lobby shuttles.

BACKGROUND

With the development of the electric passenger elevator and structural steel, the first skyscraper, the 20 story Home Insurance office building, constructed in Chicago in 1884 was born. As we turn the corner into the 21st century, plans for multiple use mega high rise buildings (more than 100 stories) are already on the electronic drawing boards (CAD CRT'S). Just as the electric elevator was critical to the development of the first skyscraper, the application of innovative elevator designs and proper elevatoring solutions will be of paramount importance to the successful operation of a mega high rise structure.

The impetus to build mega high rise complexes has clearly shifted from North America to Asia. High land costs, difficulties in assembling suitable building sites, the construction of multi use complexes and the prestige that developing countries glean from building high rise towers are some of the reasons that most of these planned projects are to be located in Asia. Seven out of ten of the current top ten high rise buildings are being constructed in Asia. Shanghai, China is rapidly becoming the mega high rise capitol of the world.

ELEVATOR DESIGN PARAMETERS

Before we review the elevatoring designs in the current top 10 high rise buildings list it would probably be helpful to review the conventional parameters for group passenger lift design so that the inexperienced designer will be aware of the limitations:

- The practical limit for the number of lifts located in a single group is 8 elevators.
- The number of upper floors located in each elevator zone (office building) should not exceed 15 - 16 levels (18 - 20 for a double deck group).
- Typical office building local lift sizes are 1350kg, 1600kg and 1800kg, single decks; double decks are written as 1350kg/1350kg, 1600kg/1600kg, or 1800kg/1800kg.
- Typical sky lobby/observation deck lift sizes are 1800kg, 2040kg, 2250kg or 2500kg, single deck or double deck.
- The human body can tolerate acceleration rates of about .9m/sec^2 - 1.5m/sec^2 in a vertical plane without discomfort. Most current high rise elevator gearless hoist machines (ACV^{3}F or D.C.) can easily achieve these limits.
- Elevator speed is utilized to partially overcome travel distances; typical gearless elevator speeds are 2.5 m.p.s., 3.5 m.p.s., 4.0 m.p.s., 5.0 m.p.s., 6.0 m.p.s., 7.0 m.p.s., 8.0 m.p.s., 9.0 m.p.s., 10.0 m.p.s. or the world's fastest lifts at 12.5 m.p.s.
- Roped elevators have a maximum practical travel of about 600m.

ELEVATOR ZONE DESIGNS

If we think of high rise buildings being provided with multiple zones of local elevators serving about 15 upper levels/zones (20 levels/zone double decks) in an office building environment, then the typical project would have the following number of local zones:

BUILDING STORIES	NUMBER OF ELEVATOR ZONES SINGLE DECKS	DOUBLE DECKS
15	1	1
30	2	2
45	3	3
60	4	3

After 60 stories, we do not normally add a 5th zone of single decks or a 4th zone of double decks because the elevator shafts simply take up too much building space. Instead, we would consider adding a sky lobby located above the first set of local zone elevators that is served by it's own express sky lobby shuttles and then start the local service zones all over again. The twin, 110 story, New York World Trade Center Towers are a perfect example of this type of elevator design. The towers are composed of 3 each, 36 story building zones stacked on top of one another. Each 36 story group is served by 4 zones of 6 each, single deck local

elevators with the 3 groups separated by two sky lobbies. The sky lobbies are served by their own express shuttle elevators.

The beauty of the stacked, sky lobby scheme is that it permits the local elevator zones to be placed on top of one another with the effect of adding more than one elevator to each hoist way slot.

In the past 25 years, most skyscrapers that had heights in excess of 60 stories with sky lobbies were equipped with single deck, sky lobby shuttles. The largest single deck shuttles ever constructed are located in the New York World Trade Center Towers. Each tower has 23 of these shuttles, 4500kg @ 8.0m.p.s. that provide service to the two sky lobbies and were planned to serve a tower population of about 22,500 persons. Because of decreased rental densities, the current populations are about 12,000 - 13,000 persons/tower. The Chicago Sears Tower is a similar height and size building that is also equipped with two sky lobbies and a current population of about 12,000 persons. However, the sky lobbies are served by 14 double deck shuttles with duties of 2500kg/2500kg @ 7.0m.p.s. and 8.0m.p.s. Sears Tower was the World's first application of double deck sky lobby shuttle elevators.

Depending upon the building height, the typical floor plate size, the expected population density (number of sq.m./person), zone populations, and expected population turnover rates, we would expect that the future elevator designs for multi-use, mega-high rise buildings would almost always include the use of one or more sky lobbies. Nine out of ten of the current high rise list buildings have sky lobbies.

In Asia, the high land costs require the design of tall slender, multi-use towers with floor plans that are usually smaller and population densities that are more extreme than their U.S. counterparts. With these building parameters, a conventional, single deck elevatoring approach, even utilizing sky lobby shuttles, would result in excessive amounts of valuable building core space being devoted to lift shafts. Therefore, the application of double deck elevators for both the sky lobby shuttles and local zone lifts is becoming most common because fewer lifts are required (about a 60-70% double deck vs. single deck ratio is appropriate).

A double deck solution may cost the same as a single deck application but the savings in core space and an increase in rentable area normally results in an increased revenue stream and improved proforma for the building owners.

The top/down approach to building elevatoring (single deck or double deck) can result in an even more efficient building core as lower building zone shafts are further reduced and more local lift zones are stacked on top of one another.

MULTI-USE PROJECT STACKING

Many of the Mega-High rise projects presently being planned will be true multi-use complexes or cities within a city. The design elements of such a complex might include a subterranean parking garage, a retail component, food courts, a supermarket, a movie/entertainment center, night clubs/disco/karoke bars, office space, business/service apartments, residential apartments, a hotel, upper floor (view) restaurants, and a roof top observation level. Such a multi-use tower might even contain a roof level heliport, a retirement home, child care facilities, a hospital or medical center and even a school or college. Many of these elements require their own dedicated, elevator service so the element stacking can be critical. The normal stacking arrangement for a multi-use, high rise structure from base to top is:

- PARKING
- ARRIVAL TERMINAL
- RETAIL
- OFFICE
- HOTEL
- RESIDENTIAL
- VIEW RESTAURANTS
- OBSERVATION DECK

Many of the recommended stacking orders are logical consequences of required adjacencies. For instance, the parking facilities must be close to the street to minimize the requirement for costly spiral parking ramps or automobile lifts. The retail spaces should be close to the terminal floor(s), sky lobbies of transit spaces in order to capture the interest of people passing by and to effectively utilize escalators for vertical transport. The view restaurants and observation decks have the most spectacular views and attract the highest paying customers when they are located at the very top of the complex.

Because of their greater population densities, faster required turnover rates and reduced psychological waiting times, office spaces normally have more elevators than hotels, and hotels have more elevators than residential apartments. Therefore, it is logical to stack the hotel on top of the office floors and the residential apartments on top of the hotel. Any other arrangement would likely result in the greater number of office space elevators penetrating the hotel and/or residential spaces and reducing the number of available units. The office passenger elevator speeds would also have to be increased to compensate for the extra express travel distances required.

THE MEGA HIGH RISE TOP TEN

Except for the Bank of China project, all of the current buildings listed in the top 10 qualify as mega high rise buildings because they are all in excess of 75 stories and are equipped with one or more sky lobbies (except for the Empire State Building). The attached charts show the 10 buildings ranked by height and then by the evolutions of their elevator designs:

- The Empire State Building used 6 zones of conventional single deck lifts without the use of a sky lobby.
- The Bank of China Tower and Central Plaza utilized conventional, single deck sky lobby shuttles feeding local zones stacked on top of 4 lower zones.
- The New York World Trade Center Towers were the first buildings to have 2 sky lobbies and utilizes single deck shuttles to feed the local upper zones.
- Jin Mao uses conventional single deck shuttles to feed a hotel that is to be located on top of the office space.
- T & C Tower will be the World's first truly multi-use, mega high rise complex and utilizes conventional single deck lifts to service the two office/residential and hotel sky lobbies.
- Sears Tower is the first building to utilize double deck sky lobby shuttles with service to conventional local zones.
- Petronas Towers are the World's first application of double deck sky lobby shuttles that feed local double deck lifts.

In the future we would expect to see many more combinations of top/up and top/down double deck sky lobby shuttle to double deck local applications. For multi-use complexes, triple deck and eventually quadruple deck shared, top/down shuttles may become a reality.

ACV^{3}F GEARLESS HOIST MOTORS

Because gearless hoist motors require slow speed, high torque applications (typical R.P.M.'s are 100-125) the motors have historically been constructed as direct current units. Even today, many of the double deck local and sky lobby shuttle applications are still being provided as D.C. units. The first high speed gearless elevator motors took their electricity from the nearby D.C. street car power lines so they ran quite smoothly. As city D.C. power was phased out in favor of alternating current, the D.C. hoist motors required that the A.C. line current be converted to D.C., first by the use of motor generator sets and more recently by the use of S.C.R. drives.

For decades elevator design engineers have pursued their dream of running the gearless hoist machines directly from the line A.C. A.C. induction motors must run at synchronous speed (1625r.p.m. for 60Hz line current) in order to be efficient, so the induction motor was not a viable alternative to the D.C. gearless hoist motors then being utilized. Beginning in the mid 1980's the advent of Insulated Gate Bipolar Transistors (I.G.B.T.) permitted A.C. variable voltage, variable frequency drives to be utilized to precisely control an A.C. gearless hoist machine. ACV^{3}F hoist motors are generally smaller, more efficient and use less power than

their D.C. counterparts. The first generation of ACV³F drives and gearless hoist motors had limited speeds and lifting capacities and were only cost competitive for drives up to 1600kg and speeds below 5.0m.p.s. As the technology is refined and the amperage ratings of the I.B.G.T. power converters are increased, we will shortly see all gearless hoist motors being provided as ACV³F units.

Most of the World's major elevator manufacturers are actively developing new ACV³F gearless hoist motors and power converter/inverter drives that will have duties of up to 10,000kg @ 10.0m.p.s. Two of the manufacturers are developing A.C. gearless hoist motors that will utilize permanent magnet rotors (rare earth - Neodymium magnets). These ACV³F gearless hoist machines will be much smaller than their current A.C. machine offerings and may herald the arrival of triple deck or even quadruple deck sky lobby shuttle elevators (see attached diagrams)

BIOGRAPHY

James W. Fortune graduated from Pasadena City College with a degree in Architecture and from California State Polytechnic University with major in Architecture and Industrial Technology. After a stint in the U.S. Navy, he served with Westinghouse Elevator Division in Los Angeles for the years, then joined Lerch, Bates & Associates - Denver Headquarters - in 1971 as a staff engineer. He later became project manager and regional vice president. In 1979, he relocated to Los Angeles as the consulting firm's Vice President and West Coast zone manager, and in 1985, became the company's East Coast and West Coast vice president while relocating to the Denver Headquarters office. He obtained his MBA degree from the University of Denver in 1989 and was elected president of Lerch, Bates & Associates in 1994.

CHART 1

10 TALLEST BUILDINGS

RANKED BY HEIGHT

HEIGHT RANK	BUILDING	LOCATION	YEAR CONSTRUCTED	STORIES	HEIGHT (M)	USE
1	PETRONAS TOWER 1	KUALA LUMPUR MALAYSIA	1997	88	452	OFFICE/PRIVATE OBSERVATION DECK (87TH FLOOR)
2	PETRONAS TOWER 2	KUALA LUMPUR MALAYSIA	1997	88	452	OFFICE/PRIVATE OBSERVATION DECK (87TH FLOOR)
3	SEARS TOWER	CHICAGO USA	1974	110	442	OFFICE/PUBLIC OBSERVATION DECK (103TH FLOOR)
4	JIN MAO	SHANGHAI CHINA	1998	88	421	OFFICE/HOTEL/PUBLIC OBSERVATION DECK (89TH FLOOR)
5	ONE WORLD TRADE CENTER	NEW YORK USA	1972	110	417	OFFICE/TOP OBSERVATION RESTAURANT (110TH FLOOR)
6	TWO WORLD TRADE CENTER	NEW YORK USA	1973	110	415	OFFICE/PUBLIC OBSERVATION DECK (110TH FLOOR)
7	EMPIRE STATE BUILDING	NEW YORK USA	1931	102	381	OFFICE/PUBLIC OBSERVATION DECK (86TH FLOOR)
8	CENTRAL PLAZA	HONG KONG (CHINA)	1992	78	374	OFFICE/PRIVATE OBSERVATION DECK (73RD FLOOR)
9	BANK OF CHINA	HONG KONG (CHINA)	1989	70	369	OFFICE/PRIVATE OBSERVATION DECK (70TH FLOOR)
10	T & C TOWER	KAOSHING TAIWAN	1998	88	348	RETAIL/ENTERTAINMENT CENTER/RESIDENTIAL/OFFICE/HOTEL/ PUBLIC OBSERVATION DECK (80TH FLOOR)

CHART 2

10 TALLEST BUILDINGS

PASSENGER ELEVATOR EVOLUTIONARY RANKING

HEIGHT RANK	BUILDING	PASSENGER ELEVATOR DESIGNS			COMMENTS
		SKY LOBBY(S)	SHUTTLES	LOCALS	
7	EMPIRE STATE BUILDING	-	-	SINGLE DECKS	CONVENTIONAL, MULTI ZONE (6 ZONES) SINGLE DECK ELEVATORING; HIGH RISE ZONE FEEDS TOWER/OBSERVATION ELEVATORS
9	BANK OF CHINA TOWER	ONE (43rd)	SINGLE DECKS (1600KG)	SINGLE DECKS	CONVENTIONAL TOP/UP SHUTTLE ELEVATORING
8	CENTRAL PLAZA	ONE (46th)	SINGLE DECKS (2050KG)	SINGLE DECKS	CONVENTIONAL TOP/UP SHUTTLE ELEVATORING
5 & 6	WORLD TRADE CENTER 1&2	TWO (44th & 78th)	SINGLE DECKS (4500KG)	SINGLE DECKS	CONVENTIONAL TOP/UP SHUTTLE ELEVATORING 2 INTERZONE, SKY LOBBY SHUTTLES SEPARATE SINGLE DECK OBSERVATION SHUTTLES
4	JIN MAO	ONE (54th)	SINGLE DECKS (1600KG)	SINGLE DECKS	CONVENTIONAL TOP/UP HOTEL SHUTTLE ELEVATORING SEPARATE SINGLE DECK OBSERVATION SHUTTLES
10	T & C TOWER	TWO (12th & 39th)	SINGLE DECKS (OFFICE 1800KG) (HOTEL 2040KG)	SINGLE DECKS	CONVENTIONAL TOP/UP OFFICE & HOTEL SHUTTLE ELEVATORING SEPARATE SINGLE DECK OBSERVATION SHUTTLES
3	SEARS TOWER	TWO (33rd & 34th, 66th &67th)	DOUBLE DECKS (2250KG/2250KG)	SINGLE DECKS	SPLIT LEVEL, TOP/UP SHUTTLE ELEVATORING HIGH ZONE SHUTTLES CAN STOP @ BOTH SKY LOBBIES SEPARATE SINGLE DECK OBSERVATION SHUTTLES (CONVERTING TO DOUBLE DECKS)
1 & 2	PETRONAS TOWERS	ONE (41st & 42nd)	DOUBLE DECKS (2100KG/2100KG)	DOUBLE DECKS	SPLIT LEVEL, TOP/UP SHUTTLE ELEVATORING
PLANNING STAGE BUILDINGS					
WOULD BE #4 (435M)	MILLENNIUM TOWER LONDON, ENGLAND	TWO	DOUBLE DECKS (2250KG/2250KG)	DOUBLE DECKS	SPLIT LEVEL, TOP/DOWN SHUTTLE ELEVATORING HIGH ZONE SHUTTLES CAN STOP @ BOTH SKY LOBBIES SEPARATE DOUBLE DECK OBSERVATION SHUTTLES
WOULD BE #1 (460M)	INTERNATIONAL WORLD FINANCIAL CENTER SHANGHAI CHINA	ONE	DOUBLE DECKS (1500KG/1500KG)	DOUBLE DECKS	SPLIT LEVEL, TOP/UP SHUTTLE ELEVATORING

A GLOSSARY OF ELEVATOR DESIGN TERMS

BUILDING TERMS	
SKY SCRAPER	A HIGH RISE BUILDING WITH MORE THAN ONE ZONE OF ELEVATORS
MEGA HIGH RISE BUILDING	A BUILDING WITH ONE OR MORE SKY LOBBIES AND IN EXCESS OF 75 FLOORS
MULT-USE COMPLEX	A BUILDING CONTAINING MORE THAN ONE TYPE OF TENANCY; SUCH AS A PROJECT WITH PARKING, RETAIL, OFFICE SPACES AND A HOTEL
ELEVATOR ARRANGEMENT TERMS	
TERMINAL FLOOR	A MAIN ELEVATOR DISPATCHING ENTRY/EXIT FLOOR(S)
SKY LOBBY	A TERMINAL FLOOR(S) LOCATED IN SOME UPPER PORTION OF A BUILDING WHERE PASSENGERS CAN TRANSFER BETWEEN THE SHUTTLE ELEVATORS AND LOCAL ELEVATORS
SHUTTLE ELEVATOR	A LARGE ELEVATOR (SINGLE DECK OR DOUBLE DECK) THAT IS UTILIZED TO TRANSPORT PERSONS BETWEEN TERMINAL FLOORS; NORMALLY USED BETWEEN GROUND FLOOR TERMINAL(S) AND UPPER FLOOR SKY LOBBY(IES)
LOCAL-ZONE ELEVATORS	A GROUP OF ELEVATORS THAT ARE DISPATCHED FROM A TERMINAL FLOOR(S); CAN BE A SKY LOBBY
SINGLE-DECK ELEVATOR	A SINGLE ELEVATOR CAR IN A SINGLE FRAME
DOUBLE-DECK ELEVATOR	TWO ELEVATOR CARS RIGIDLY ATTACHED, ONE ON TOP OF ANOTHER AND LOCATED IN THE SAME ELEVATOR FRAME
TRIPLE, QUADRUPLE, QUINTUPLE DECK ELEVATORS	THREE, FOUR OR FIVE ELEVATOR CARS ATTACHED TO THE SAME ELEVATOR FRAME AND STACKED ON TOP OF ONE ANOTHER
GROUP ELEVATORS	TWO OR MORE ELEVATORS RESPONDING TO THE SAME HALL PUSH BUTTONS AND SERVING SIMILAR FLOORS
TOP/UP ELEVATOR APPROACH	LOCAL ELEVATORS BEING DISPATCHED UP FROM SKY LOBBY FLOOR(S)
TOP/DOWN ELEVATOR APPROACH	LOCAL ELEVATORS BEING DISPATCHED UP AND DOWN FROM SKY LOBBY FLOOR(S)
SPLIT LEVEL SERVICE	SKY LOBBY FLOORS SERVED BY MULTI DECK SHUTTLES WITH LOCAL LIFT GROUPS BEING DISPATCHED FROM DIFFERENT LEVELS

ELEVATOR MOTOR DRIVE TERMS	
ACV'F	ALTERNATE CURRENT, VARIABLE VOLTAGE, VARIABLE FREQUENCY POWER CONVERTERS AND/OR HOIST MACHINES
S.C.R. DRIVE	SILICON CONTROLLED RECTIFIER UNIT FOR CONVERTING A.C. LINE CURRENT TO D.C. CURRENT
I.B.G.T. CONVERTER/INVERTER DRIVE	INSULATED GATE BIPOLAR TRANSISTORS INCORPORATED IN A DRIVE THAT CONVERTS A.C. LINE CURRENT TO D.C. CURRENT, INVERTS IT TO A DIFFERENT VOLTAGE AND FREQUENCY TO PRECISELY CONTROL AN A.C. HOIST MOTOR
REGENERATIVE CONTROL	THE DRIVE PERMITS THE CURRENT PROVIDED BY THE HOIST MOTOR DURING AN OVERHAULING LOAD TO BE "REGENERATED" BACK INTO THE LINE
PULSED WIDTH MODULATION	THE TIME THE I.B.G.T. DEVICES REMAIN ON AND INVERTING FROM D.C. PLUS THE NUMBER OF PULSES IN A GIVEN TIME TO RUN THE A.C. HOIST MOTOR AT SYNCHRONOUS SPEED