

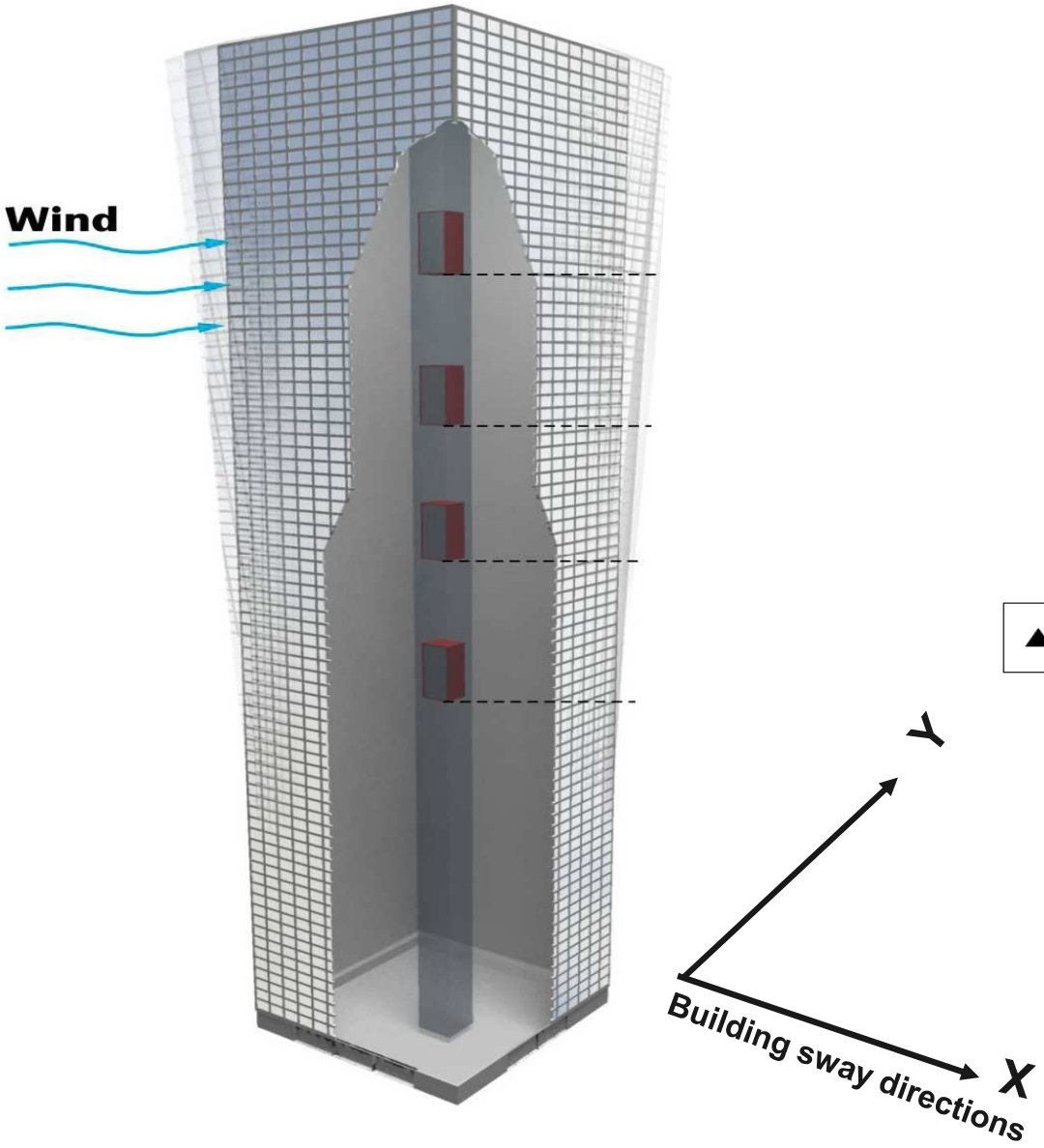
High Rise Building Design

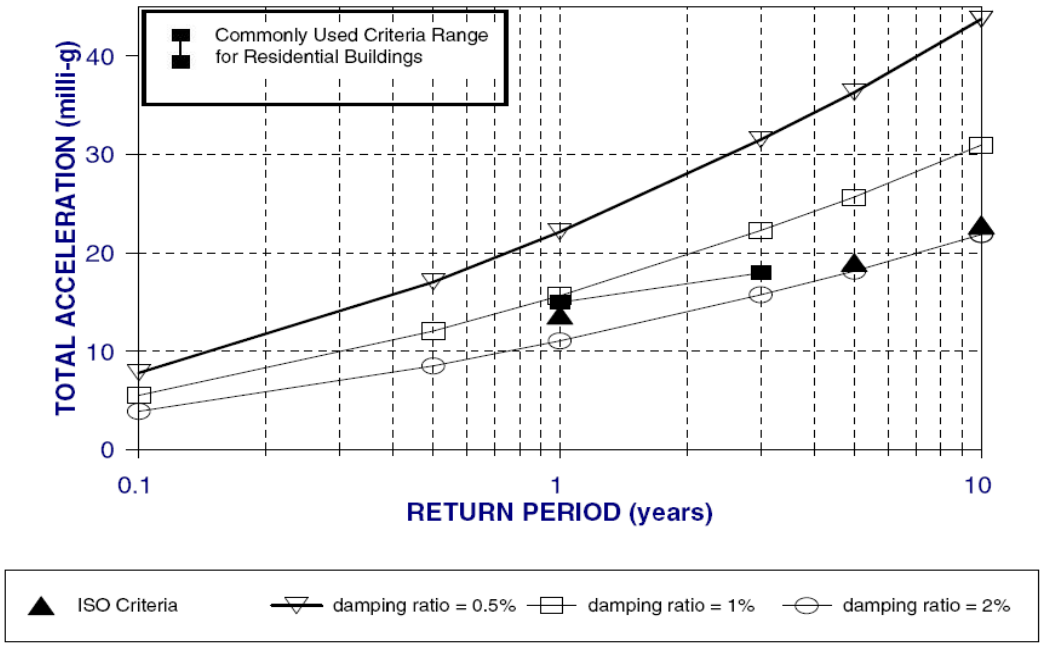
- Building sway
- Stack effect
- Piston effect
- Tunnel effect



Wind Induced Building Sway

Wind causes building to sway





Wind Induced Building Sway

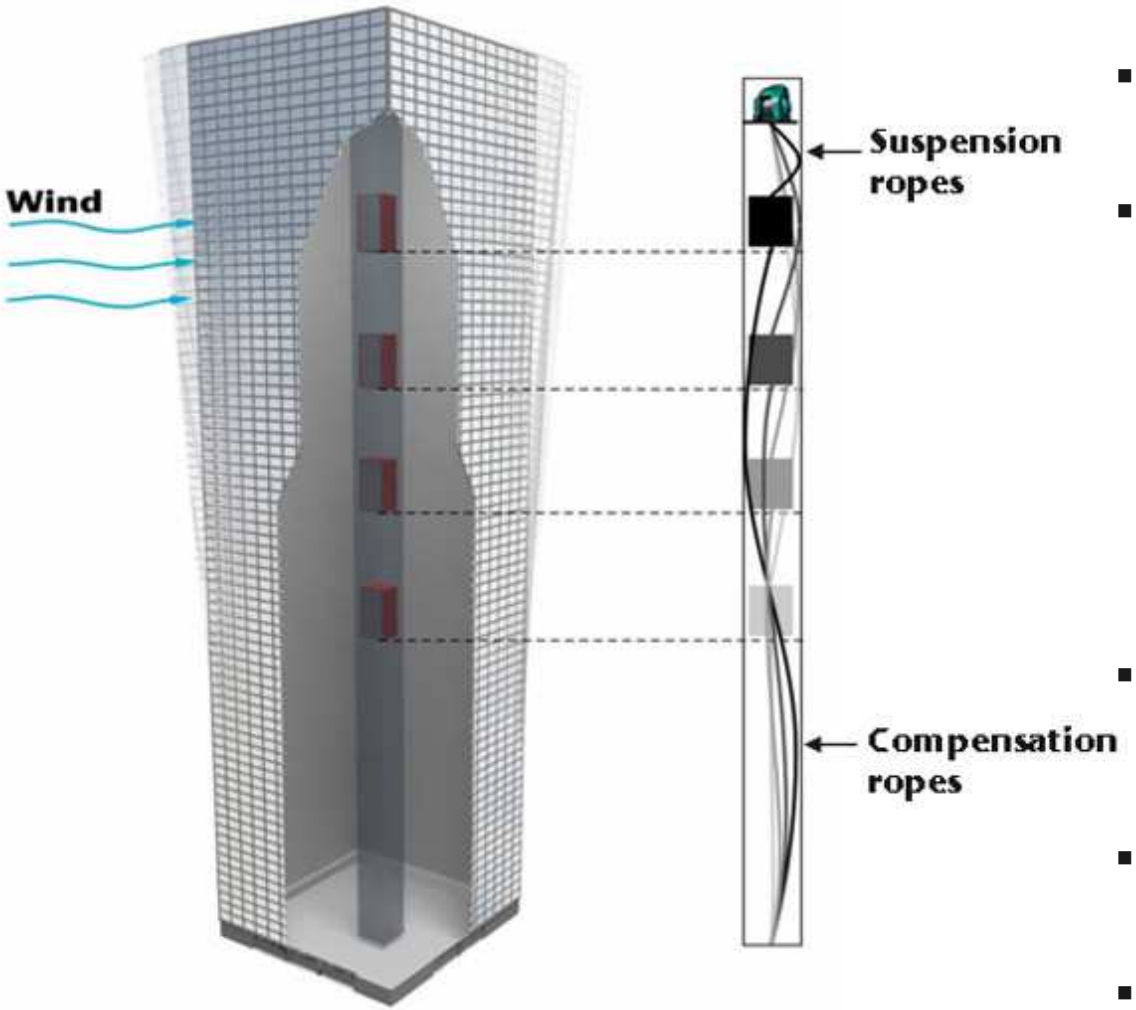


- Wind induced sway of the building may cause the elevator ropes and cables to sway also.
- In over 200m tall buildings and in slender buildings over 150m tall this may have an impact on the elevator design.
- Rope resonance and traveling cable movement cannot be completely avoided in high rise buildings.
- Our goal is to minimize risks of problems caused by building sway. Building sway may cause excessive sway in compensation ropes, overspeed governor ropes, suspension ropes and traveling cables.
- To minimize potential problems the sway behavior of ropes must be calculated. The car and tension weights should be selected accordingly.

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Wind Induced Building Sway

ANALYSIS

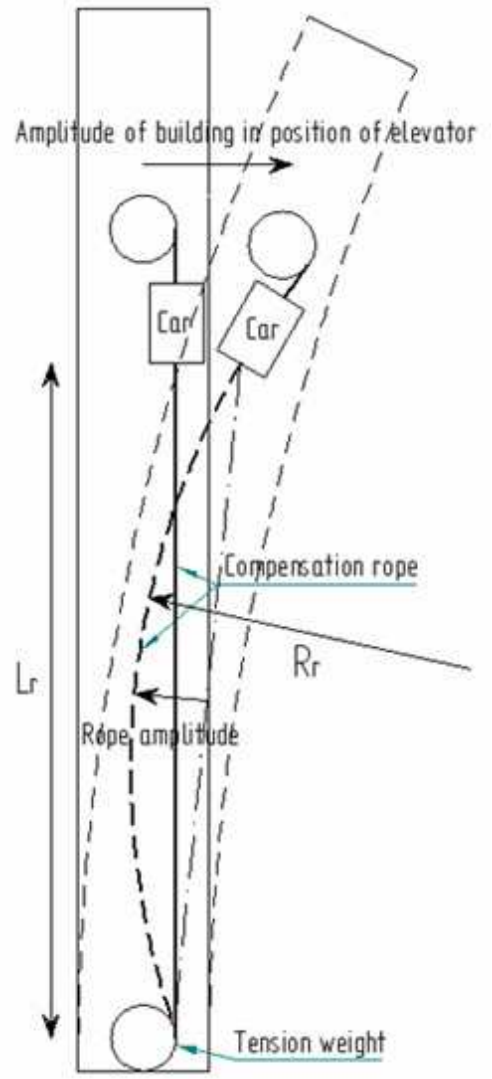


- For a rope sway analysis, we need to do the following:
- Get data of the building sway amplitudes and natural frequencies for bending modes 1&2.
- If the building natural period is not available, the period may be estimated from the building height;
  - For Heights up to 350 m:
    Period T = [0,25x{(H/350)+0,12}]xSQRT(H),
  - For heights above 350 m:
    Period T = 0,37xSQRT(H)
    where H = the building height (m).
- If the maximum amplitude is not available, the amplitude can be estimated using a maximum acceleration level of 20 milli-g.
- Identify the critical zones, where elevator rope resonances may occur.
- Apply the most suitable measures based on the position of critical zones, the amplitude of the expected rope sway, etc.

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Wind Induced Building Sway

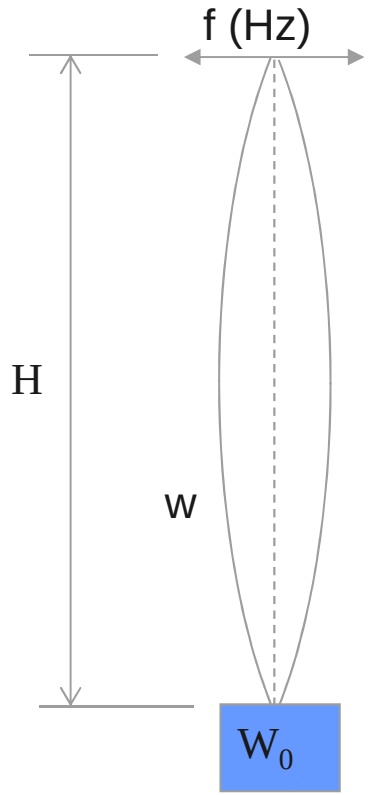
COMPENSATION ROPES



- According to the La Grange equation, the first mode of the compensation ropes is given by:

$$f = \frac{1}{2 \cdot H} \cdot \sqrt{g \cdot \left(\frac{W_0}{w} + \frac{H}{2} \right)}$$

Where: f = natural frequency (Hz)
H = Travel (m)
g = 9.81 m/s^2
W_0 = mass of compensator (kg)
w = weight of rope (kg/m)



- If the compensation rope frequency is too close to the building sway frequency, the compensation rope frequency can be tuned by changing the mass W_0.

- Where possible use fewer, large diameter compensation ropes with very long travels to prevent entanglement of the ropes.

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KONE
Rope sway cannot be completely avoided in high rise buildings.

Wind induced sway effect on vertical transportation



First implications:

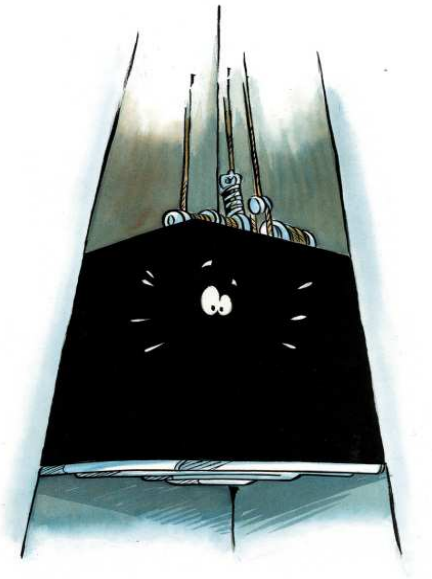
- Reduced ride comfort

  (increased lateral quacking & noise levels)
- Unpleasant experience
- Typically occurs in both end of the shafts
- Overall operation is trouble free



Higher winds:

- Ropes are colliding with elevator components
- Components are damaged in the shaft
- Queuing in the lobby & levels
- Trouble free operation can not be guaranteed



Need for solutions???

- Yes, certainly ...



Storm winds:

- Ropes are getting stuck
- Serious damage to the elevator
- Elevator out of order
- Queuing in the lobby & levels
- Takes time to put elevator back in service

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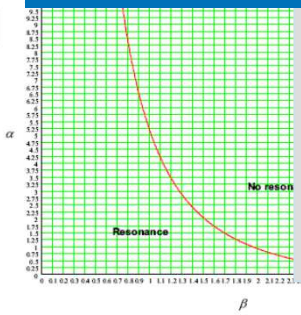
KONE Sway solution - Engineering process

Building & Elevator characteristics



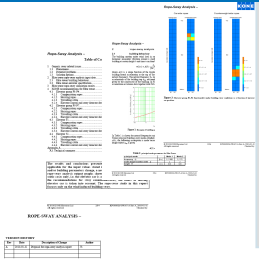
- Building natural frequency
- Building height
- Elevator space & L/O
- Max. elevator travel
- Etc.

Basic resonance check



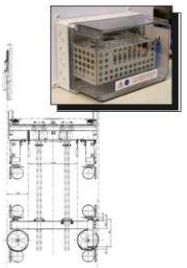
- Is resonance a problem?
  - Compensation ropes?
  - Suspension ropes?
  - Other components?

Advanced sway analysis



- Building sway report
- Building bending mode
- Building acceleration return periods.
- Etc.

Solution proposal to customer

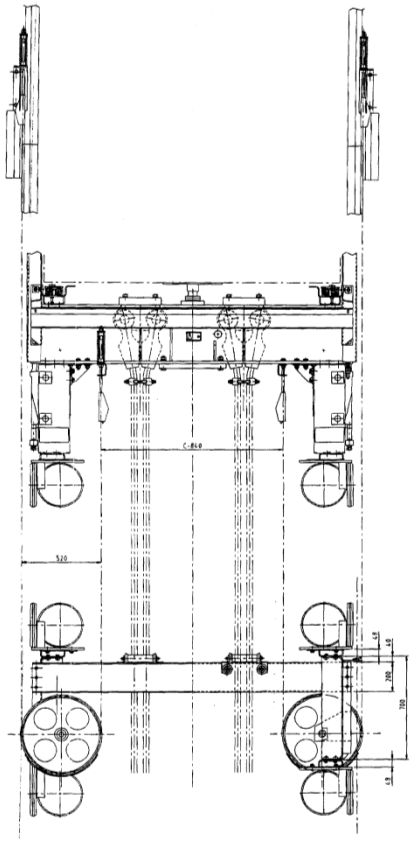


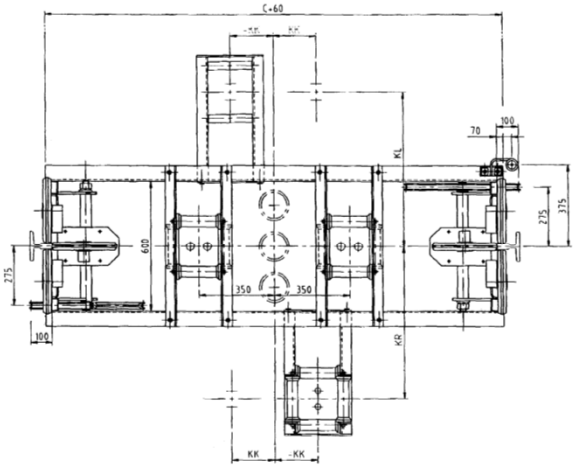
- Electrical protection equipment
- Mechanical protection equipment
- Elevator operation in high wind & storm modes

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Wind Induced Building Sway

FOLLOWER CARRIAGE



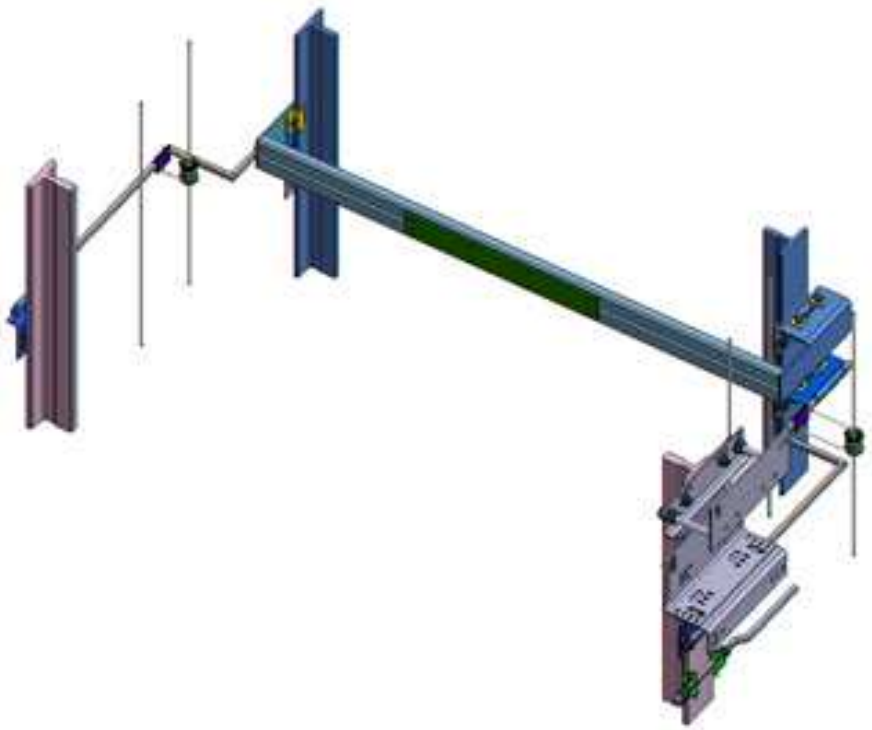


- If we need to add too much mass to the compensator, the first mode of the compensation ropes can be prevented by using a follower carriage.
- If a Follower Carriage can not be used (too small pit), use sufficient compensation weight to find a safe parking position at a none resonant location.
- Use sufficiently deep pits to fit the Follower Carriage and/or the large diameter compensator device.

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Wind Induced Building Sway

OTHER MEASUREMENTS



- Use counterweight tie-brackets in large travel elevators to limit rope sway at the counterweight side.
- Governor ropes can be held from moving with a click-clack rubber system at the side fixed to the car, and fixed tie-loops around the free end of the rope.

- **Important:**

  When elevators can not be maintained at the normal speed (rope sway is excessive, causing heavy vibration in the car), the speed of the elevators needs to be reduced.

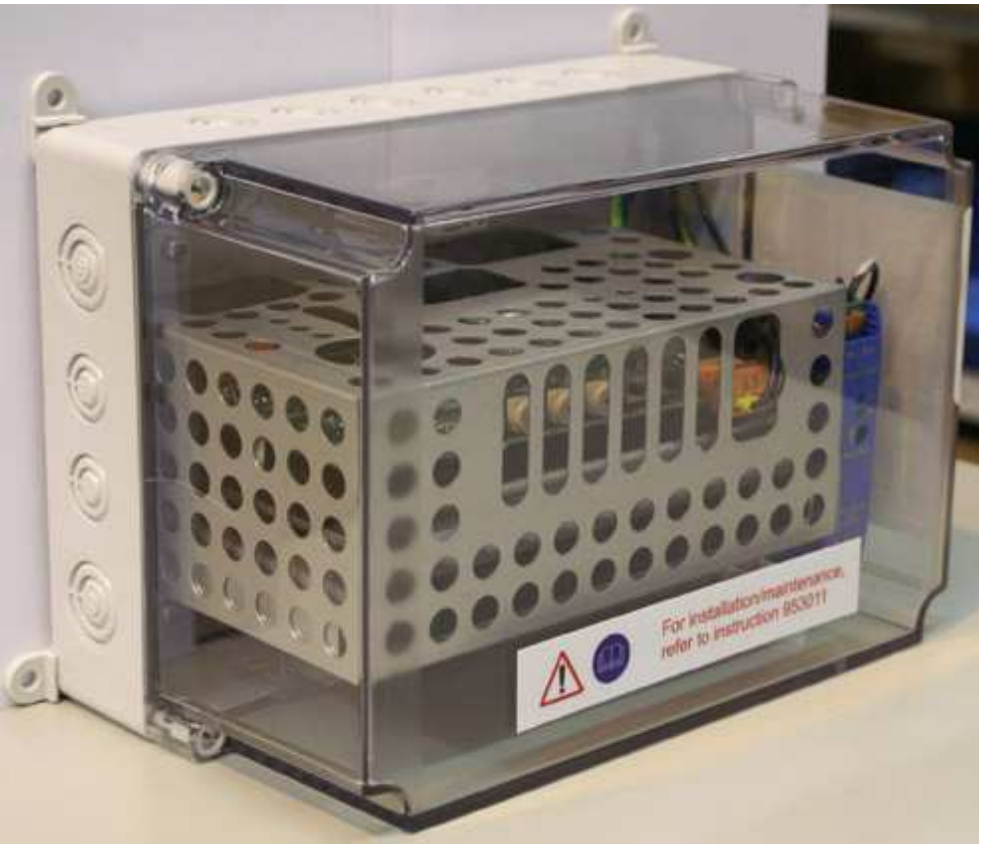
  Passengers need to be warned to leave the car as soon as possible if an elevator needs to stop at resonant floors.

  Stopping at resonant floors should be minimized or prevented.

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Wind Induced Building Sway

BUILDING SWAY DETECTOR (1)



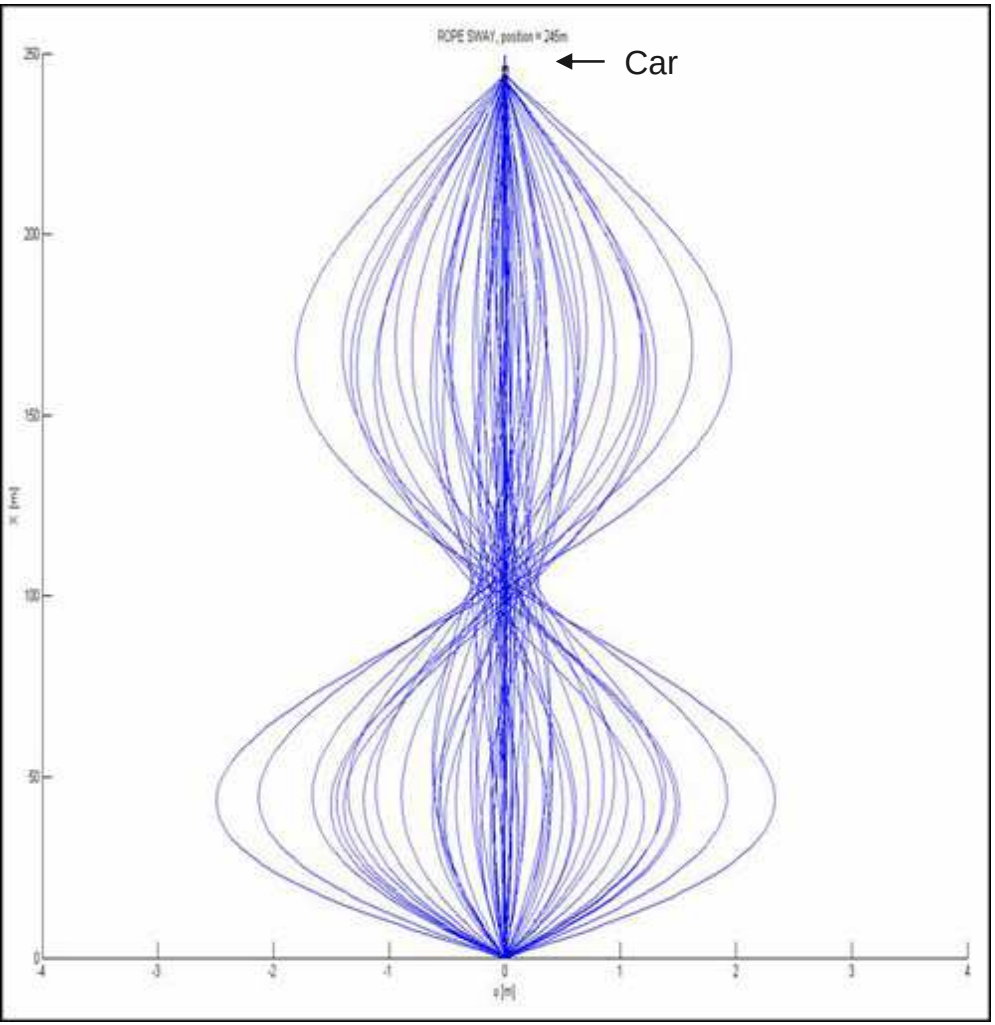
Building sway detector

- The building sway detector is an elevator group specific device located in the machine room to measure the sway of a building and activates when preset thresholds are exceeded.
- The device gives signals to the elevator controller, which determine how the elevator behaves during high wind and storm operation mode. This is to reduce excessive movement of suspension ropes, compensation ropes and traveling cables when building sway exceeds certain limits.
- The device is meant to be used on high-rise elevators with a travel of 250 meters or more, or elevators located in slender buildings such as TV-towers with a travel of 150 meters or more.

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Wind Induced Building Sway

BUILDING SWAY DETECTOR (2)



Compensation rope sway

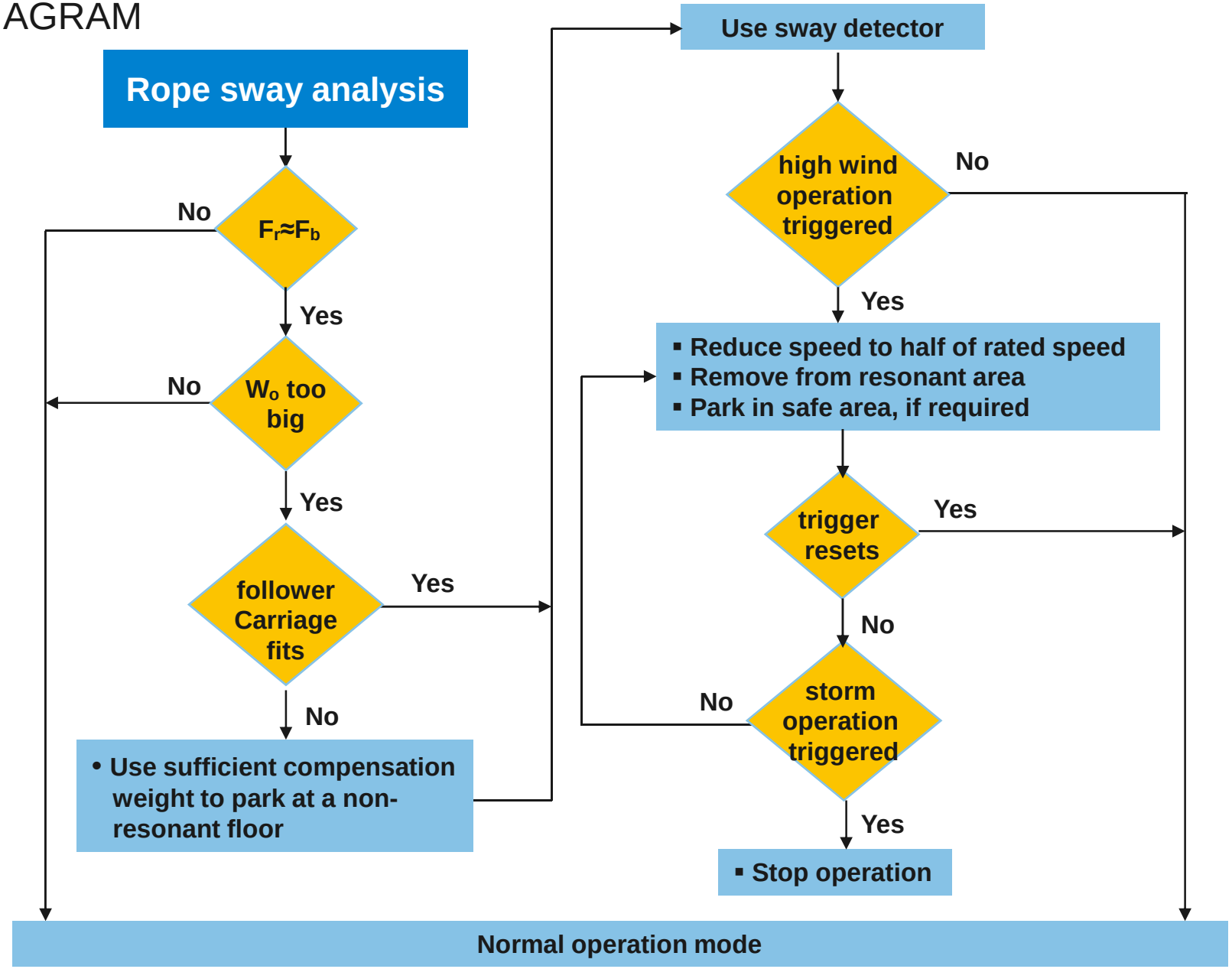
- When a building sway detector is used, the elevator operation is divided into two modes:
- **High wind operation mode:** the 1st trigger level reduces the elevator speed to half of rated speed. The sway detector has an adjustable timer. At half speed mode, if there are no car /landing calls, elevators will park immediately at a designated safe parking floor. When the timer set up time has elapsed, elevators return to the normal mode.
- **Storm operation mode:** when the 2nd trigger level activates, elevators will serve existing car calls and cancel given landing calls, and will not accept new car/landing calls. After the existing car calls are served, elevators will park immediately at the designated safe parking floor. When the 2nd trigger level times out, elevators return to the high wind operation mode.

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Wind Induced Building Sway

ANALYSIS DIAGRAM

Where:
F_r=compensation rope frequency
F_b=building sway frequency
W_o=compensator mass



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Example:
Trump International Hotel and Tower, Chicago

Sway data analysis

Some Background



- Building Sway Detector and Rope Sway Protection Equipment have been installed in Trump Tower, Chicago
- A camera system was installed in one elevator shaft to monitor the rope sway and to verify simulation models
- A laptop PC in the machine room starts video recording when building sway exceeds pre-set limit
- In addition to recorded videos, the system constantly saves sway data, weather data and elevator position

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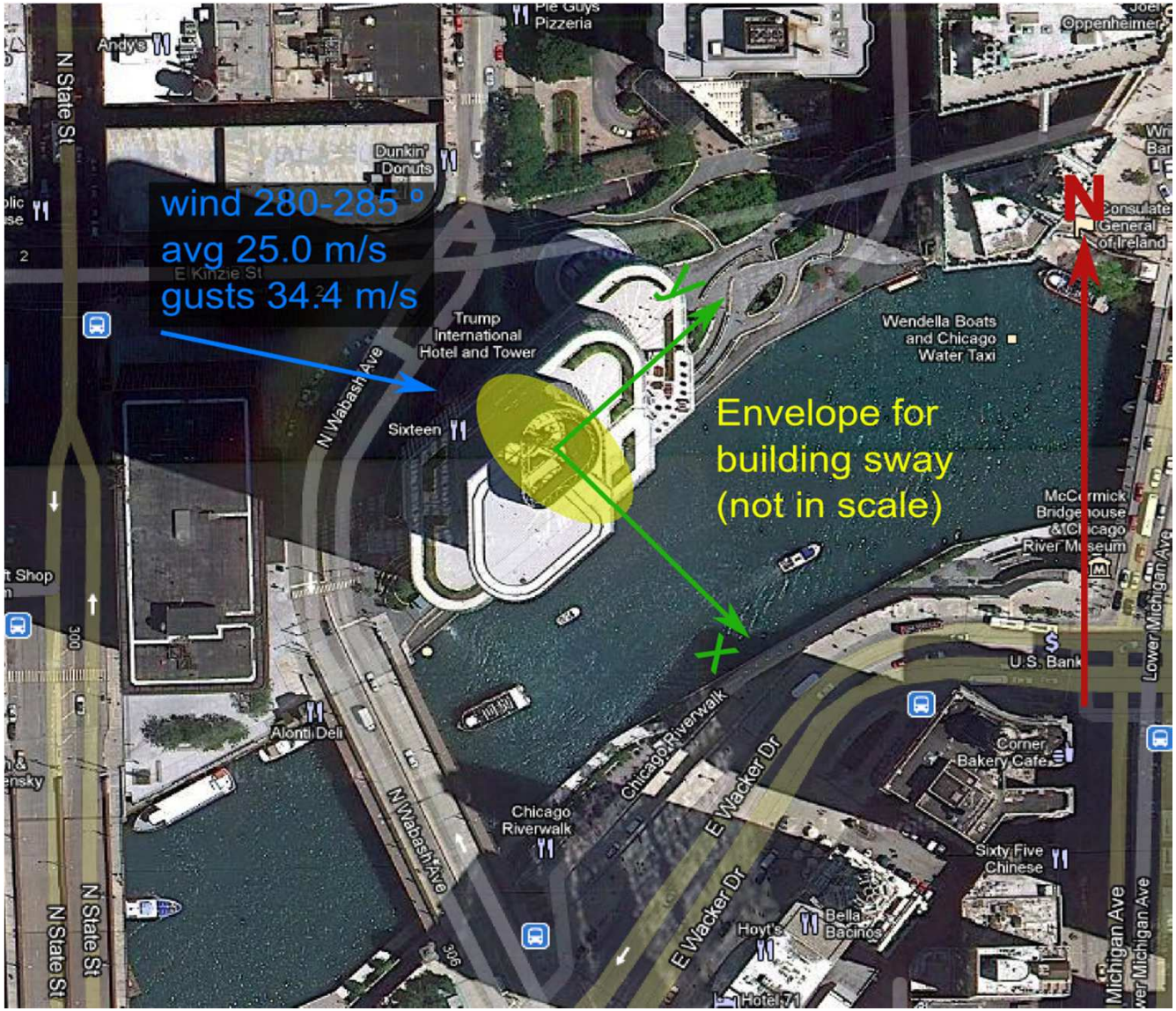
Storm on June 18, 2010



- A severe thunderstorm hit Chicago on June 18, 2010 around 15.30 CST.
  - The average wind speed was up to 25 m/s with gusts over 34 m/s
  - The wind direction was between 280-285°
- Video information and data were saved, until power was lost
  - Just before the power outage, we were able to see elevators stopping at the storm mode parking floor

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Storm on June 18, 2010

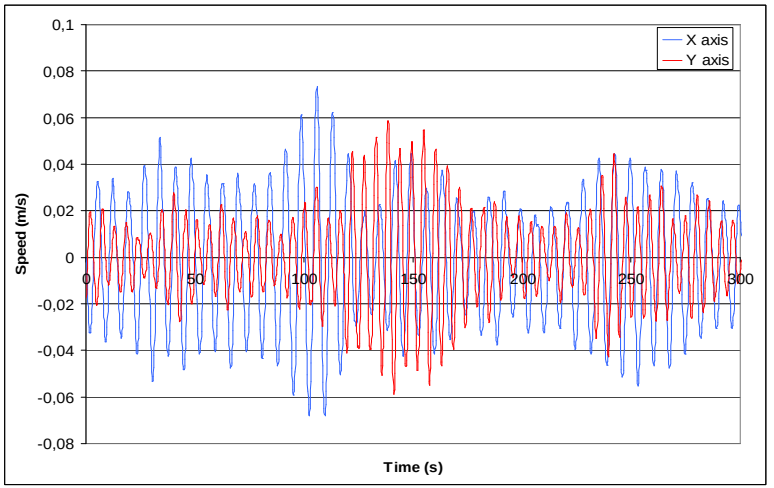


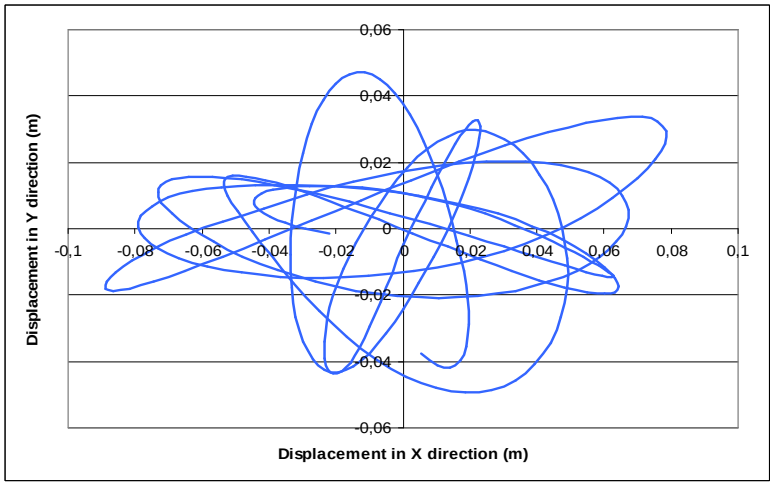
- Map © Google
- Note X and Y direction

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Storm on June 18, 2010, data

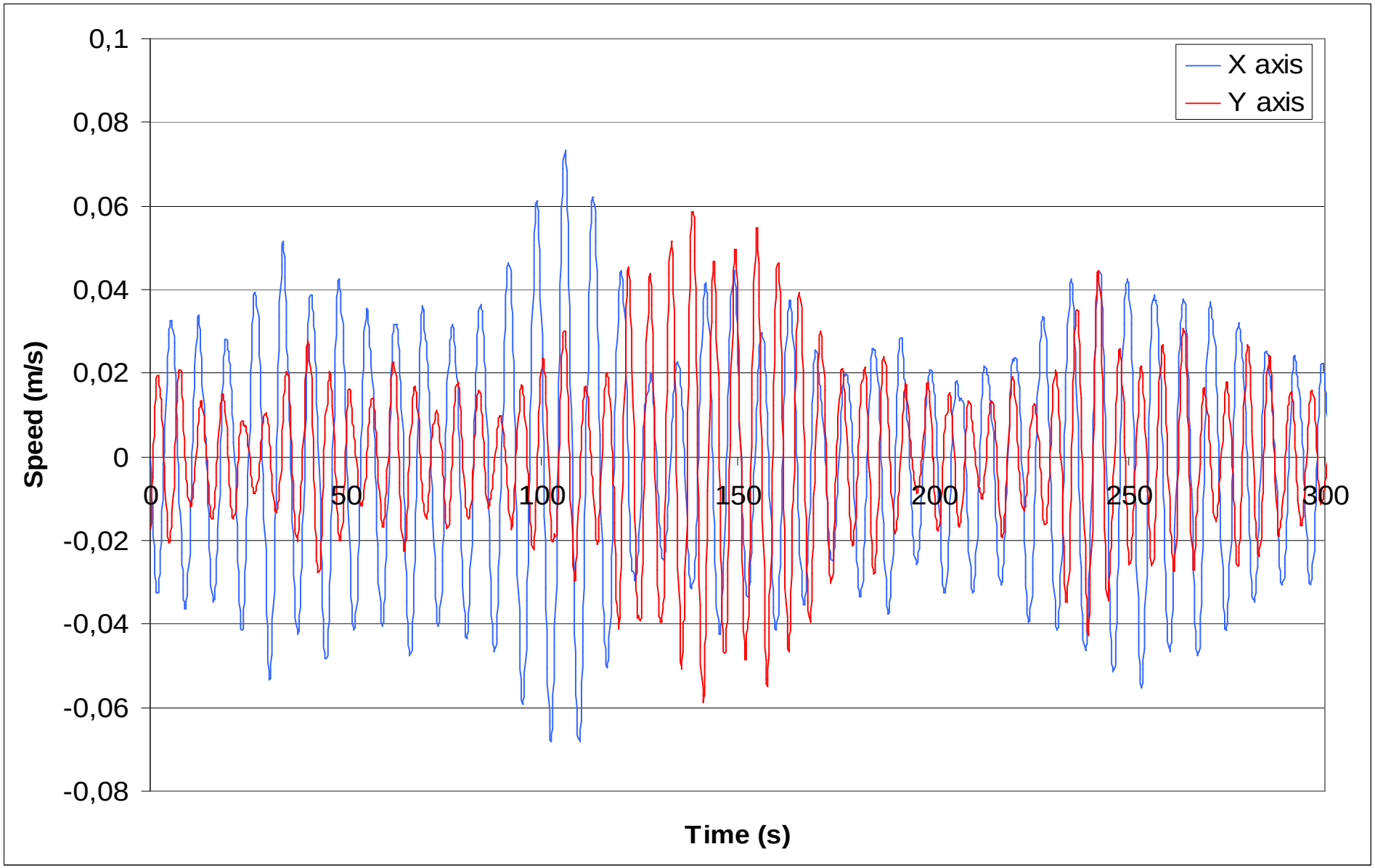
- Acceleration data is saved with a 5 Hz measurement rate, for both X and Y direction in a 1 mg resolution
- During the storm:
  - Peak acceleration in X-direction was 10 mg, and 7 mg in Y-direction
  - Peak speed was 7 cm/s in X-direction and 6 cm/s in Y-direction (upper graph)
  - Peak sway amplitude was 8 cm in X-direction and 6 cm in Y-direction (building movement in 50 s time frame between 87-137 sec seen in the lower graph)
  - Measured frequency was 0.139 Hz in X-direction and 0.183 Hz in Y-direction





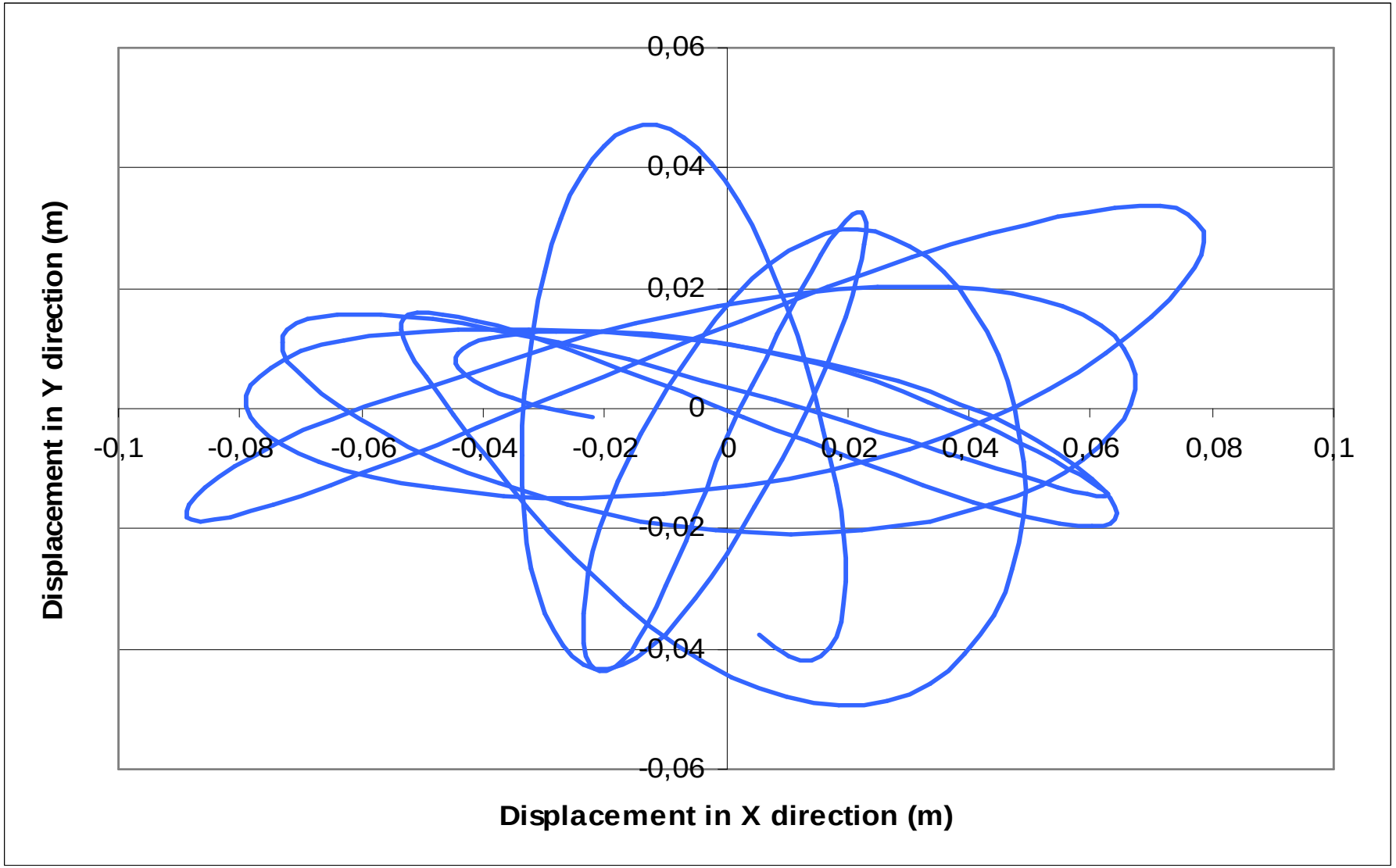
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Storm on June 18, 2010, data



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Storm on June 18, 2010, data



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Storm on June 18, 2010, video

- Video recorded near the storm mode parking floor.
- First, the elevator on the background stops on the parking floor
- Then also the nearest elevator does the same thing
- Shortly after that, recording ends due to the power outage



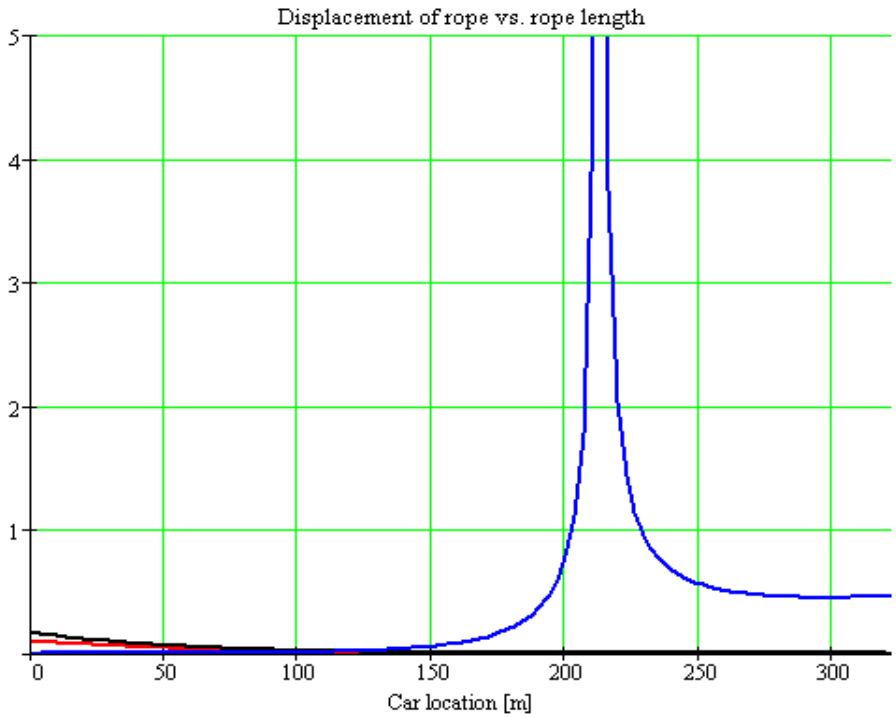
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Example:
KL118, Elevator T19, Kuala Lumpur

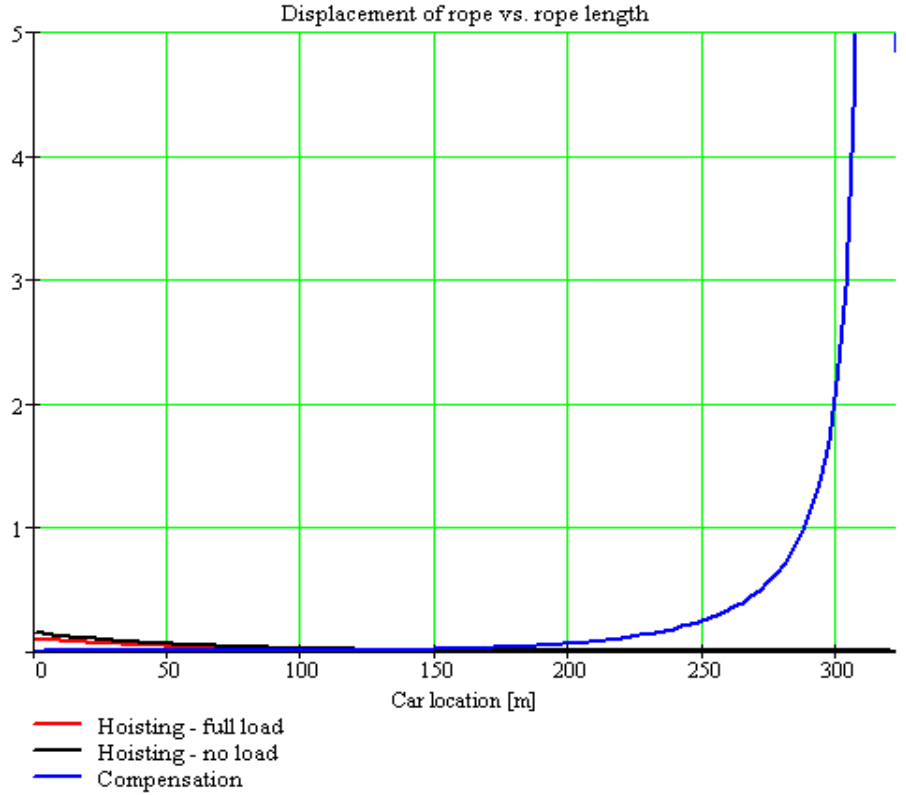
Sway data analysis

KL118 Rope Sway Studies

Results of mass de-tuning T19



Comp mass 2200 kg
With hydraulic compensator

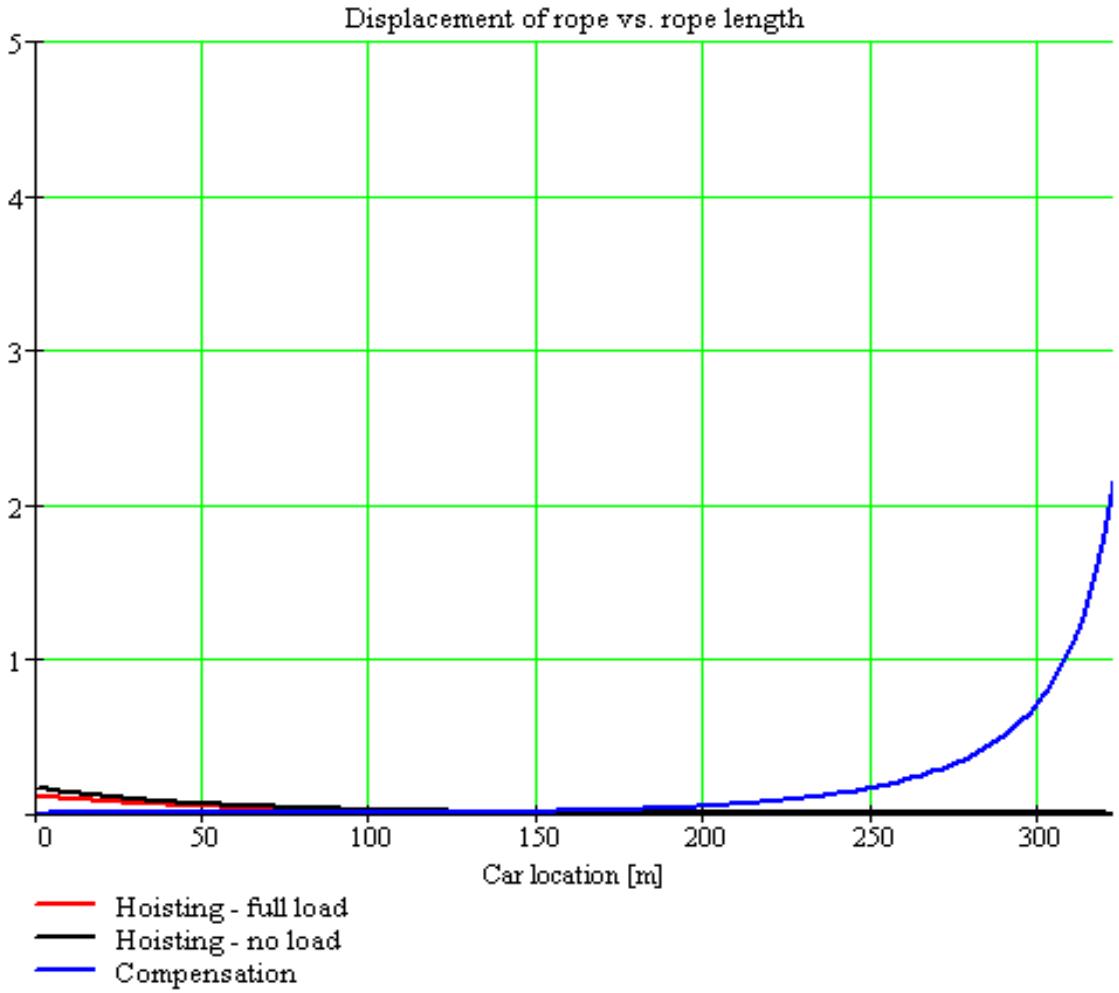


Comp mass 8000 kg
Also requires 2 extra suspension and 2 extra compensation ropes for sufficient safety factor (1900 kg extra moving mass, 9900 kg extra weight on sheave)

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KL118 Rope Sway Studies

Results of mass de-tuning T19



Comp mass 12000 kg
Also requires 5 extra suspension and 5 extra compensation ropes for sufficient safety factor (4750 kg extra moving mass, 16750 kg extra weight on sheave)

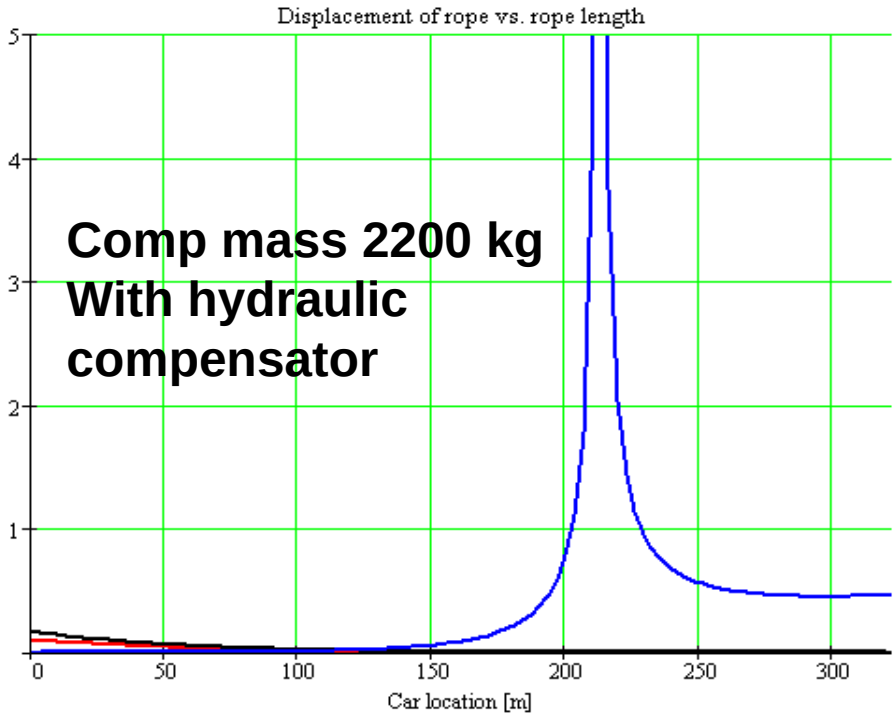
De-tuning is simply not effective enough with steel ropes, it will increase moving masses and thus energy consumption and will increase future rope replacement costs clearly.

This is one reason why KONE only uses 2200 kg in T19

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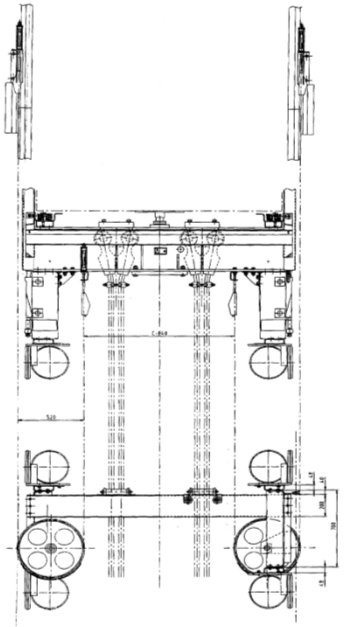
KL118 Rope Sway Studies

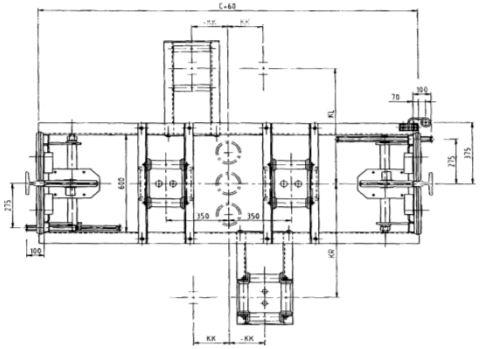
Results of mass de-tuning T19



Final building frequencies

Final building frequencies are typically 20 – 30% higher than in the structural calculations (Joint study made by SOM and KONE using KONE's sway detector).





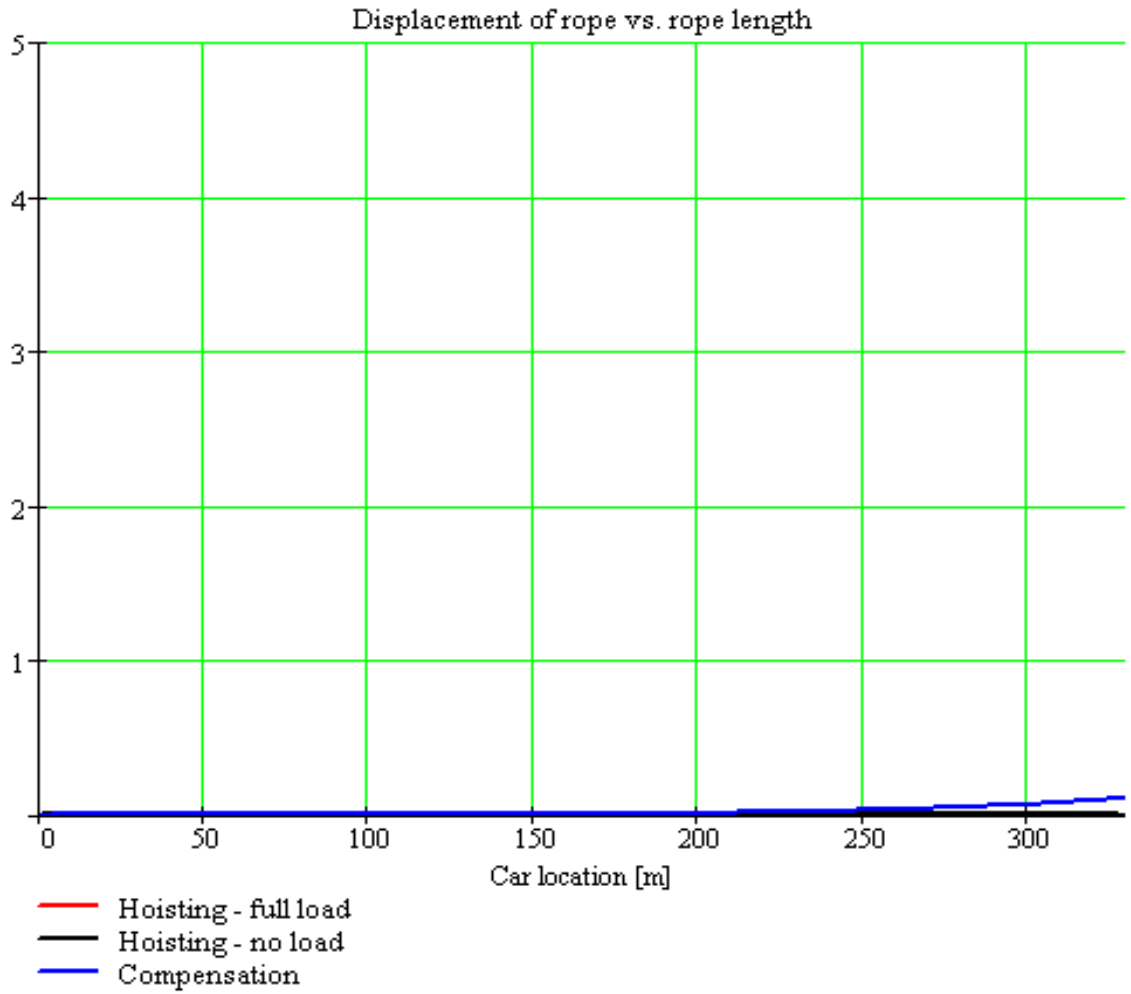
Follower Cariage

With only 2200 kg, the resonance at higher frequency will coincide with approximately mid-shaft. In such conditions a follower carriage is very helpful as it introduces a node.

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KL118 Rope Sway Studies

Results of mass de-tuning T19



KONE UltraRope

KONE UltrRope is the most efficient way to de-tune super high rise elevators.

As the mass is only a fraction of the weight of steel ropes, the frequency is much higher and will not coincide with the building frequency.

KONE Ultra-Rope will provide ”5star” operation, while at the same time reducing energy consumption and rope replacement needs.

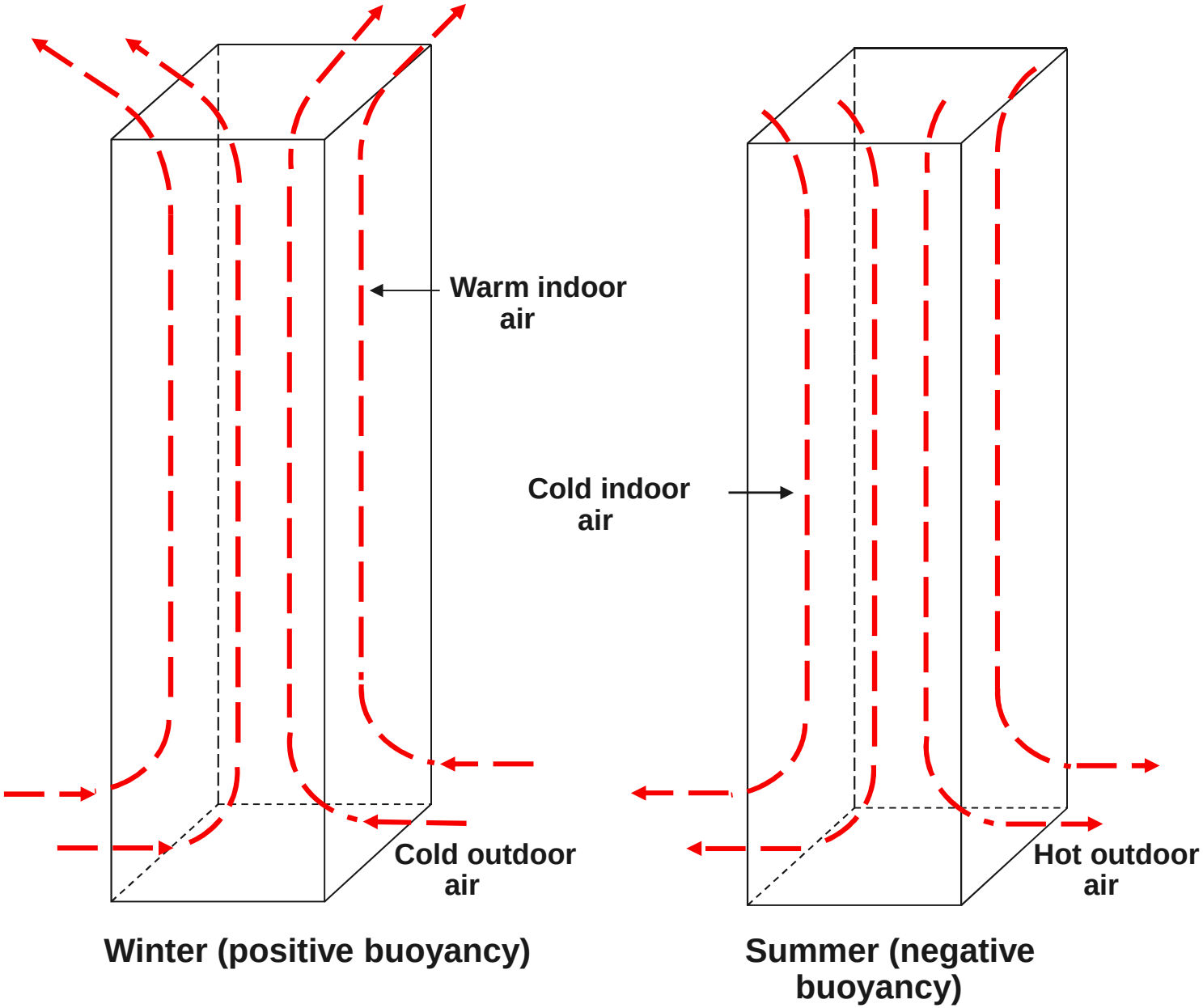
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Dedicated to People Flow™
KONE
Marriott



Building Stack Effect

Building Stack Effect



- Stack effect is the movement of air into and out of buildings, and is driven by buoyancy.
- Buoyancy occurs due to a difference in indoor-to-outdoor air density resulting from temperature and moisture differences. The result is either a positive or negative buoyancy force.
- Since buildings are not totally sealed (at the very minimum, there is always a ground level entrance), the stack effect will cause air infiltration.
- In a modern high-rise building with a well-sealed envelope, the stack effect can create significant pressure differences that must be given design consideration and may need to be addressed with mechanical ventilation.
- Especially in case of fire, the stack effect needs to be controlled to prevent the spread of smoke.

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Building Stack Effect
FORMULAE



- **The driving force for the stack effect**

  There is a pressure difference between the outside air and the air inside the building caused by the temperature difference between the outside and inside air. That pressure difference (***ΔP***) is the driving force for the stack effect and it can be calculated by:

$$\Delta P = 0.0342ah\left(\frac{1}{To} - \frac{1}{Ti}\right)$$

  where: ***ΔP***= available pressure difference, Pa
  a= atmospheric pressure, Pa
  h= height or distance, m
  To= absolute outside temperature, K
  Ti= absolute inside temperature, K

- **The flow induced by the stack effect**

  The draft or draught flow rate induced by the stack effect can be calculated by:

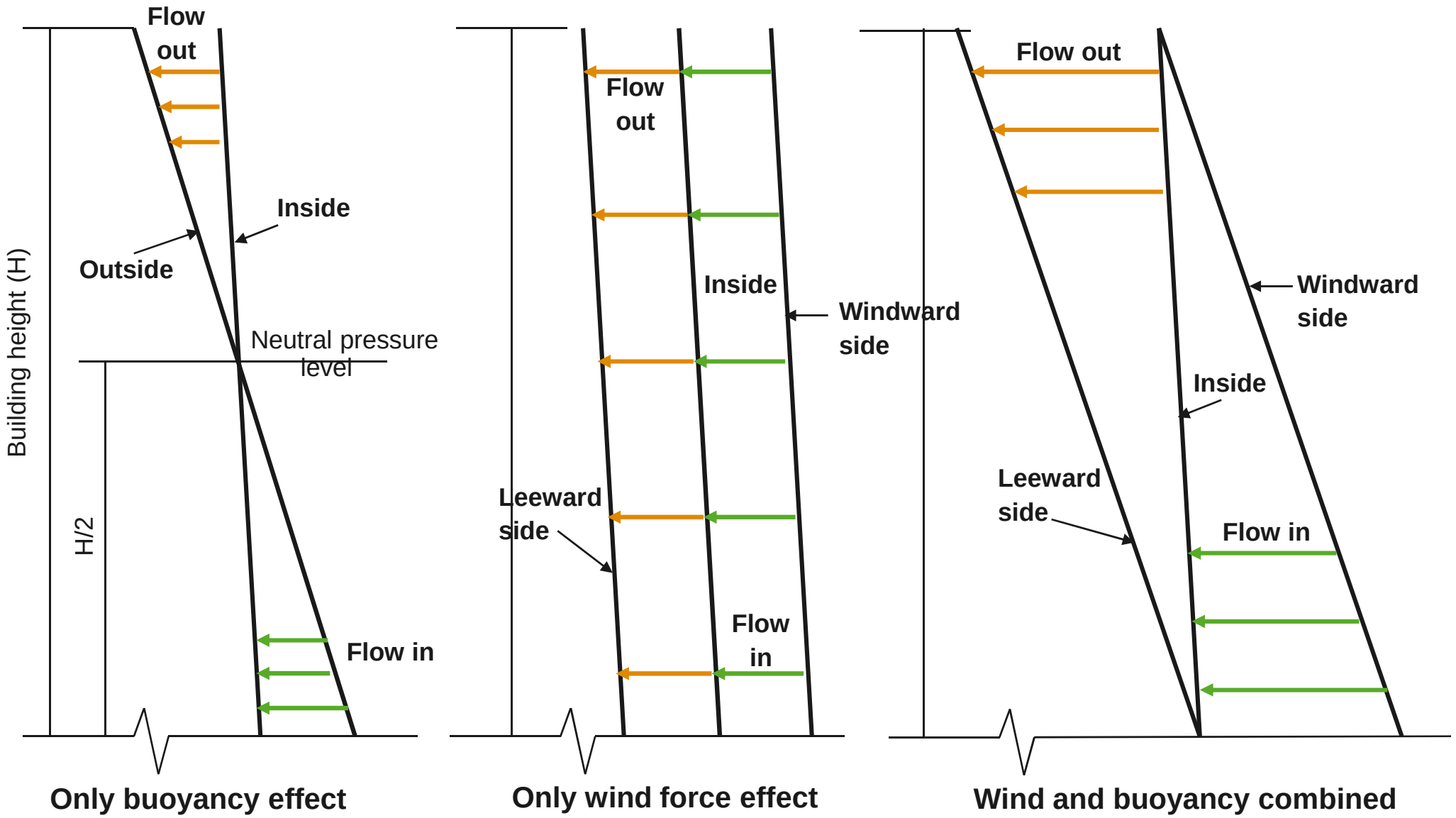
$$Q = CA\sqrt{2gh\,\frac{Ti - To}{Ti}}$$

  where: ***Q***= stack effect draft/draught flow rate, m^3/s
  A= flow area, m^2
  C= discharge coefficient (usually taken from 0.65 to 0.70)
  g= gravitational acceleration, 9.81 m/s^2
  h= height or distance, m
  Ti= average inside temperature, K
  To= outside air temperature, K

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Building Stack Effect

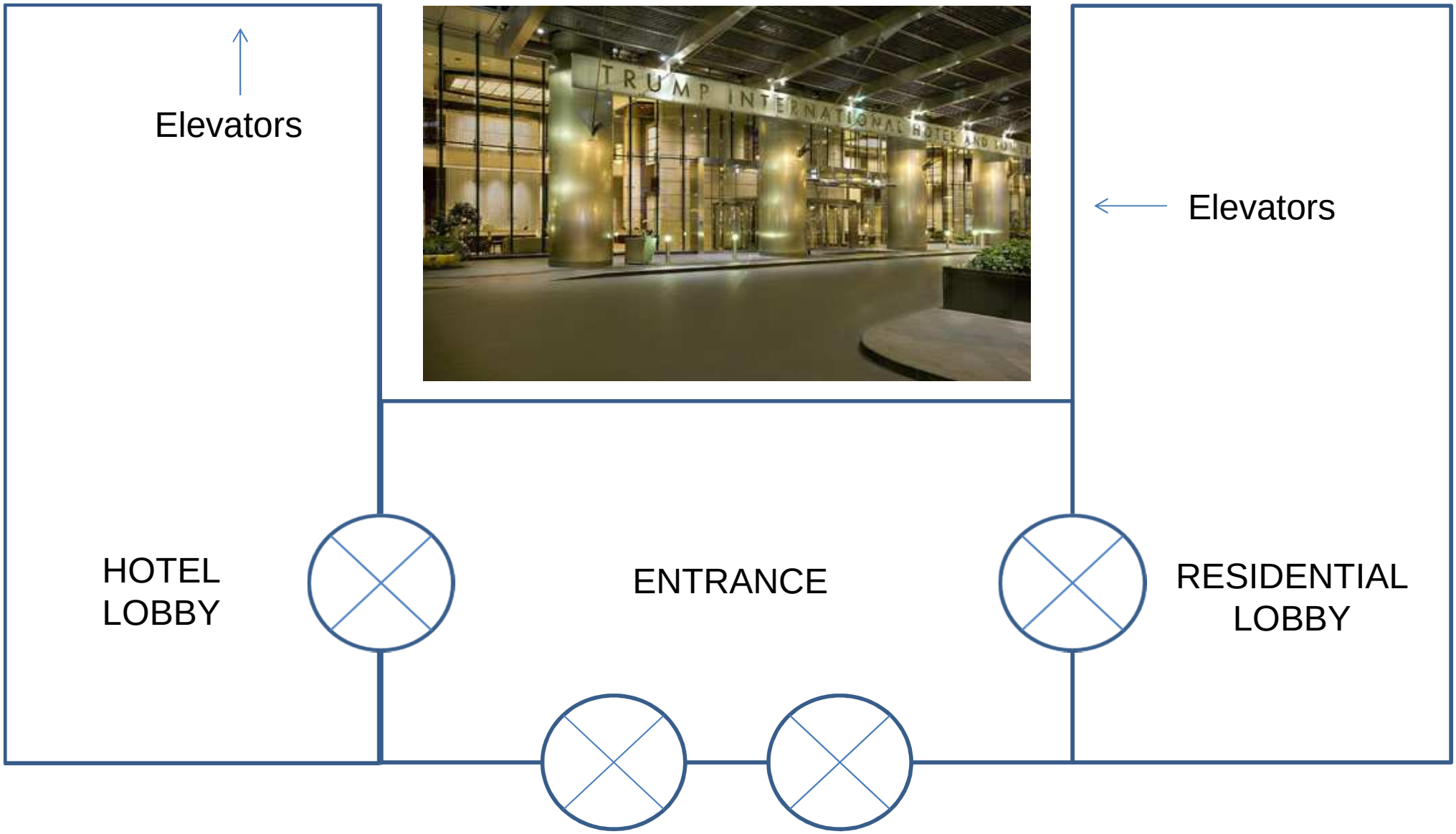
COMBINED EFFECT OF WIND AND BUOYANCY



 © KONE Corporation

Trump Chicago

Lobby Entrance



Trump Chicago

Hotel Lobby




Trump Chicago
Hotel Lobby
KONE



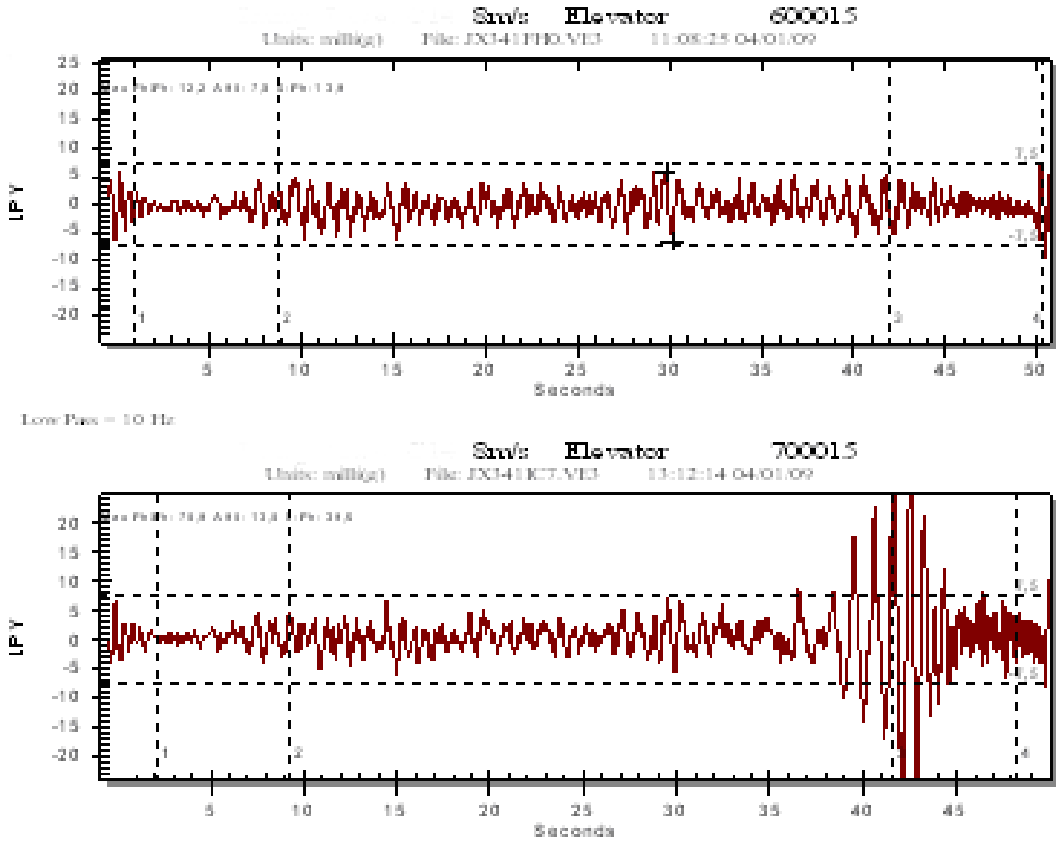




Building Stack Effect

CASE ANALYSIS

Elevator lateral quacking going up



1. Low wind day

2. high wind day (70-80 km/h)

- The lateral quacking curves shown above, have been measured in a high rise elevator with a travel of about 350 m, moving upwards from ground to the top floor. The top floors of the building are not yet sealed.
- On day with low wind conditions ride comfort is maintained throughout the full ride. On a windy day the draft at the unsealed top floors will dramatically affect ride comfort.

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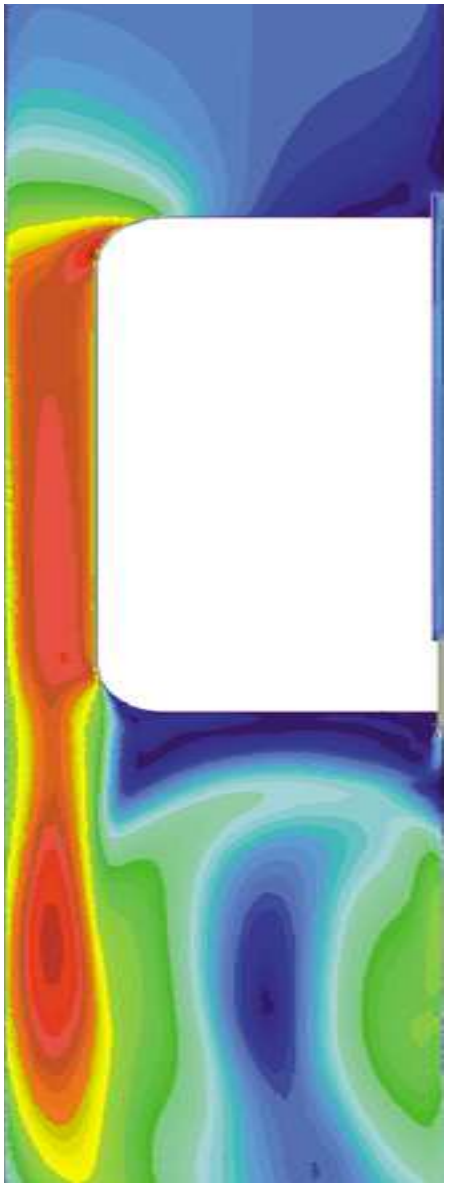


Piston Effect

Piston Effect



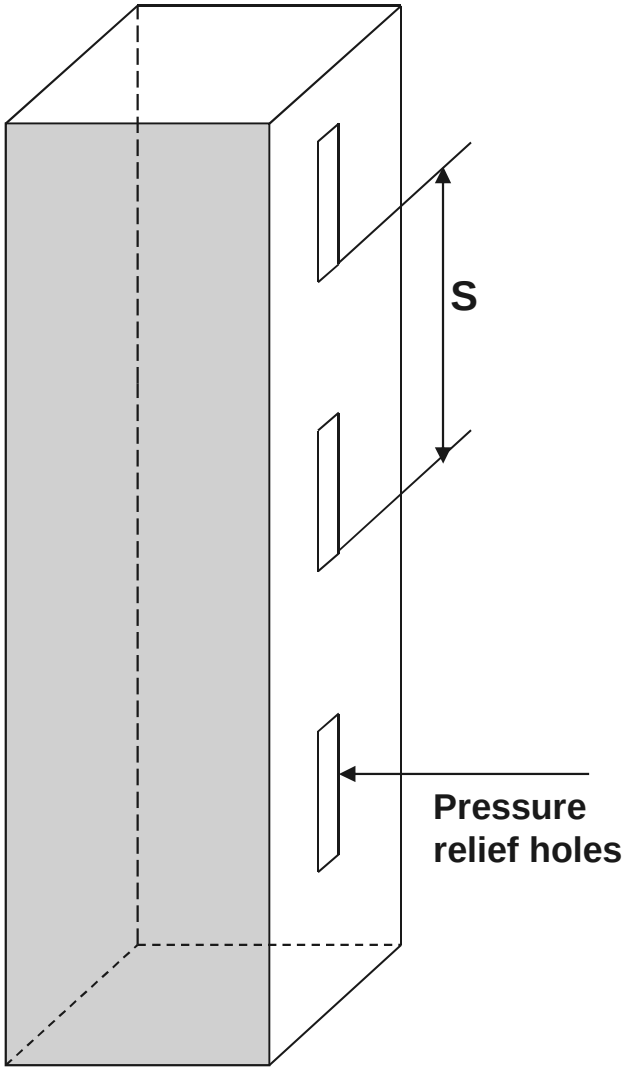
- In single shafts, the air displaced by the car is pushed into the narrow gap around the car.
- This can increase the speed of the air around the car dramatically, often to levels more than twice the speed of the car.
- This effect is called the piston effect.



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Piston Effect

PRESSURE RELIEF HOLES

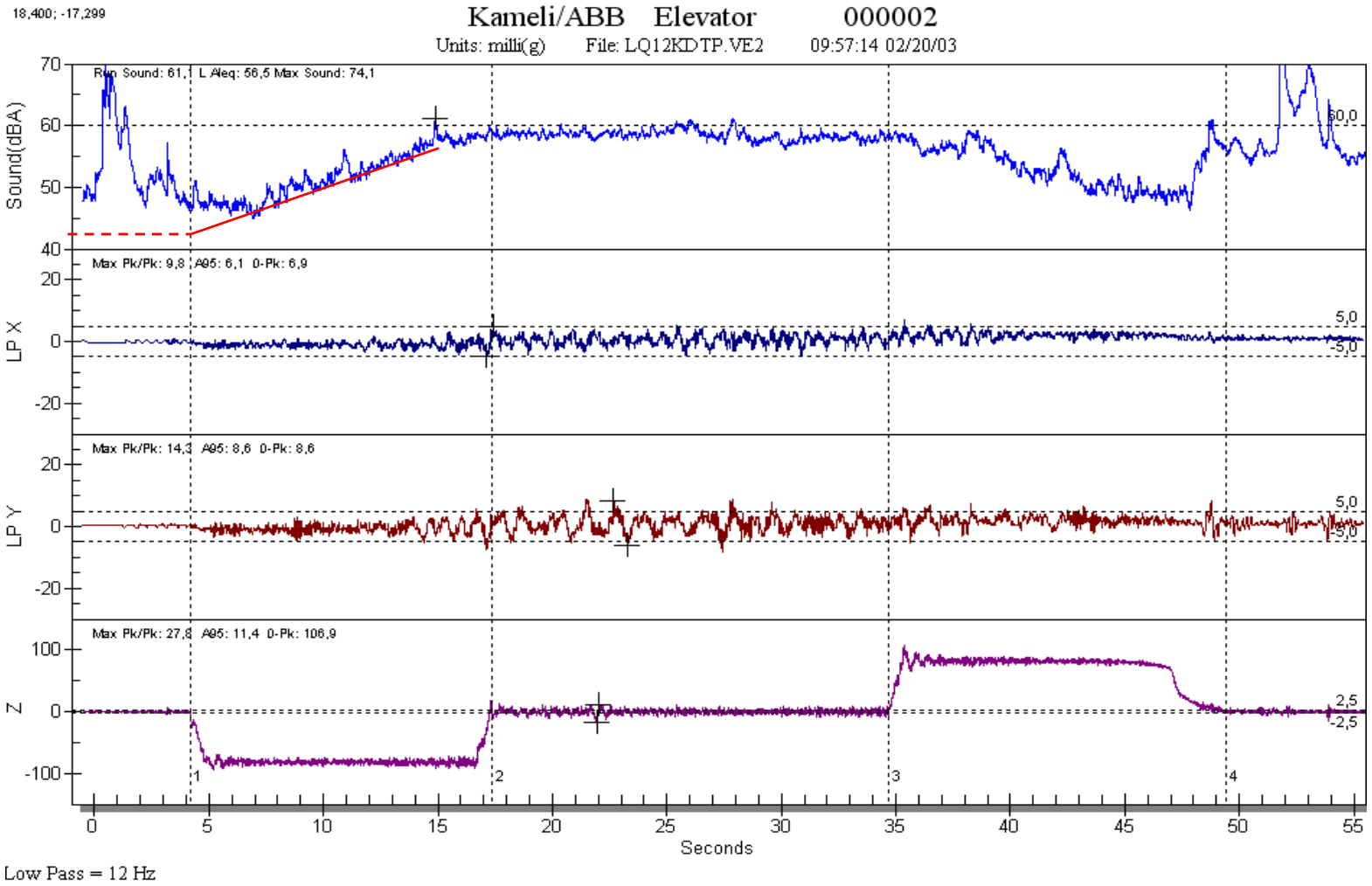


- To reduce the noise level created by the air speed around the car, pressure relief holes are needed.
- Pressure relief holes can only be used if we have an adjacent hoistway or an adjacent air duct.
- If pressure relief holes are needed in fire protected hoistways, the holes must be supplied with automatic fire dampers.
- As air compresses, the effect of pressure relief holes is limited. The distance (S) between pressure relief holes should be less than the distance covered by the elevator at rated speed in 3 seconds.

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Piston Effect

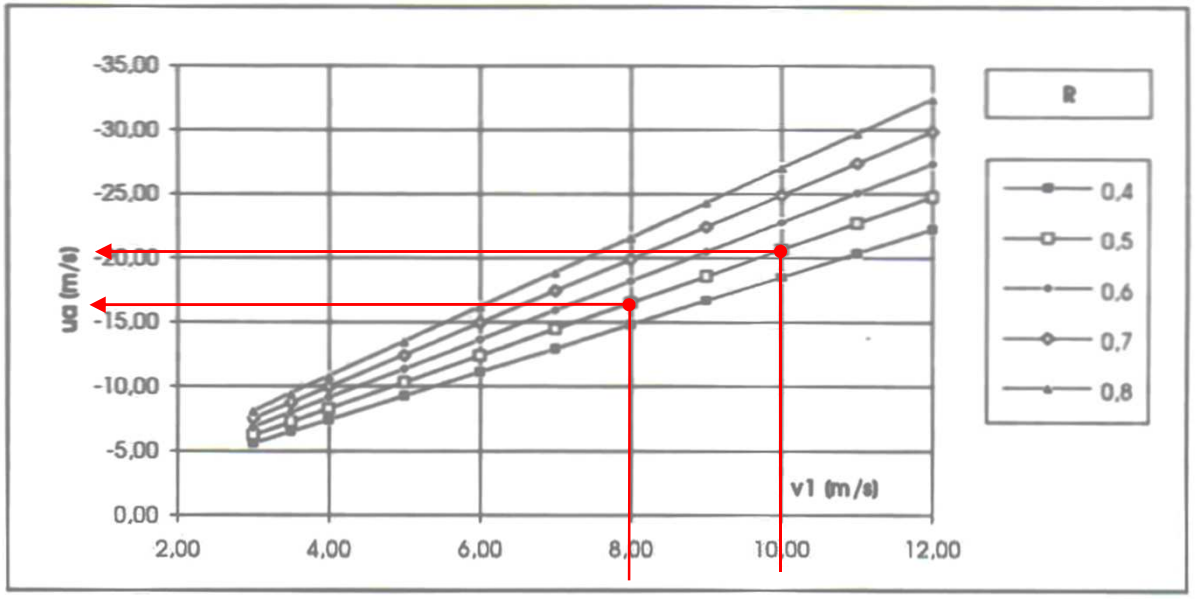
ANALYSIS



- The curve shown above is for a single shaft (the ratio of car to shaft area R=0.5) with aerodynamic shrouds: In Car Noise Level = 43+1.5 x V dB(A), where V is the speed in m/s.
- In a single shaft (R=0.5) without aerodynamic shrouds the noise level is given by:
  In Car Noise level = 45 + 2.0 x V dB(A), where V is the speed in m/s.

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Piston Effect
CALCULATION



$R = A_k/A$

where A_k = car area m^2
A = shaft area m^2

U_a = air speed around the car
V_1 = car speed

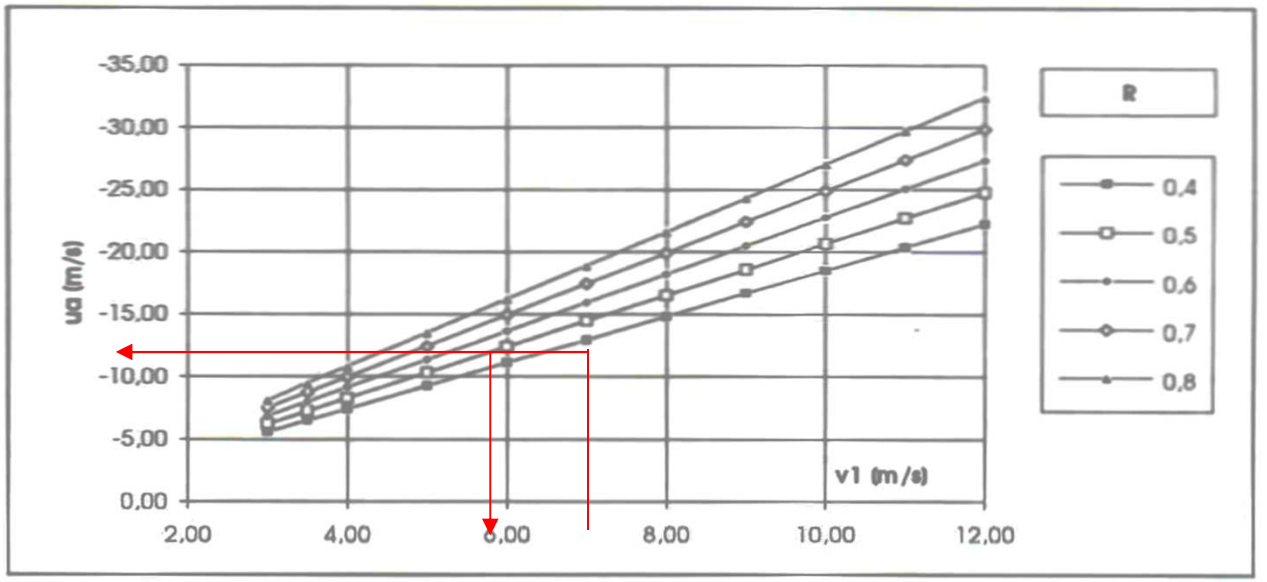
Example: calculation of size of pressure relief holes to reach required sound level.

- We want to reach an in car noise level of 55 dB(A) in a single shaft at a speed of 10 m/s.
- $A = 9\ m^2$ and $A_K = 4.5\ m^2$, $R = A_K/A = 4.5/9 = 0.5$
- At 10 m/s we will get a noise level of 43+1.5 x10 =58 dB(A) without pressure relief holes.
- To reach 55 dB(A) we need to reduce the speed of air around the car, similar to the air speed of an elevator at 8 m/s. ($55=43+1.5 \times V_1$, $V_1 = (55-43)/1.5 = 8$ m/s)
- At 10 m/s and R =0.5 we get an air speed around the car of 20.5 m/s.
- At 8 m/s and R =0.5 we reach an air speed of 16.5 m/s.
- To reduce the speed around the car from 20.5 to 16.5 m/s, we need to increase the free flow space with the reverse of the speed ratio.
- $(A_{old} - A_k) / (A_{new} - A_k) = 16.5/20.5 = 0.805$; $(9 - 4.5) / (A_{new} - 4.5) = 0.805$, then $A_{new} = 10.09\ m^2$
- Extra space needed = $A_{new} - A_{old} = 10.09 - 9 = 1.09\ m^2$
- As a square pressure relief hole has a contraction factor of 0.8, we need holes of $1.09/0.8 = 1.36\ m^2$.

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Piston Effect
CASE CALCULATION





Example: calculation of noise level in car with different R ratio without pressure relief holes.

- Hoistway size A = 3.2 (W) x 2.75 (D) = 8.8 m^2, car size A_k = 2.05 (W) x 1.425 (D) + 0.28 (door area) = 3.2 m^2.
- Elevator moving in a single shaft, what will be the noise level?
  R= A_k/ A = 3.2/ 8.8 = 0.364
  At 7 m/s and R= 0.364, we get an air speed around the car of 12.0 m/s.

- As the sound formula is for a ratio R of 0.5, we need to calculate the speed the elevator needs to have with R=0.5 to give an air speed of 12 m/s.
- With an R of 0.5, this air speed is equivalent to a rated speed of 5.75 m/s in a single shaft (see diagram).
- This will result in a sound level of 43+1.5x5.75 = 51.6 dB(A) in the car with aerodynamic shrouds.

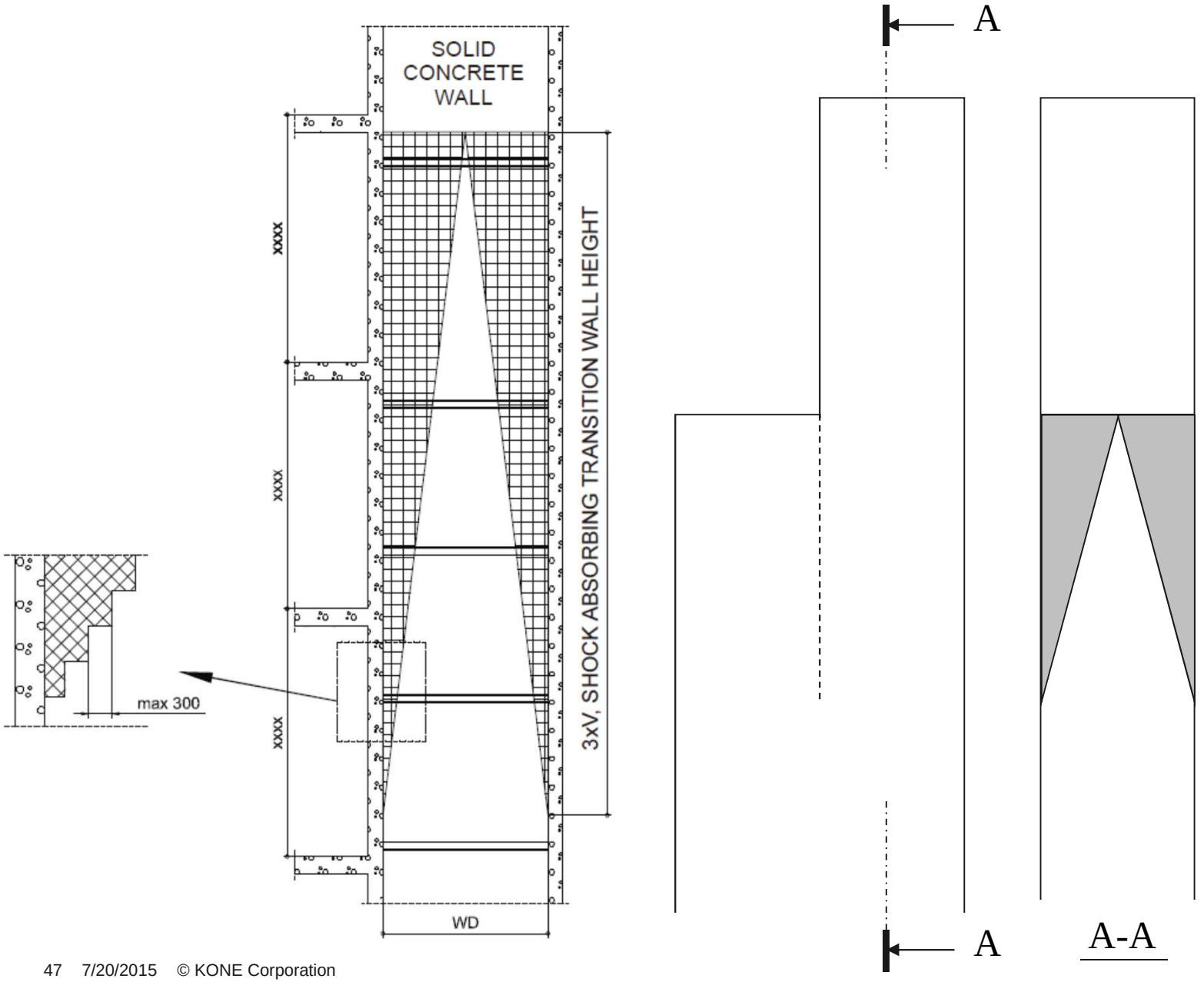
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Tunnel Effect

Tunnel Effect

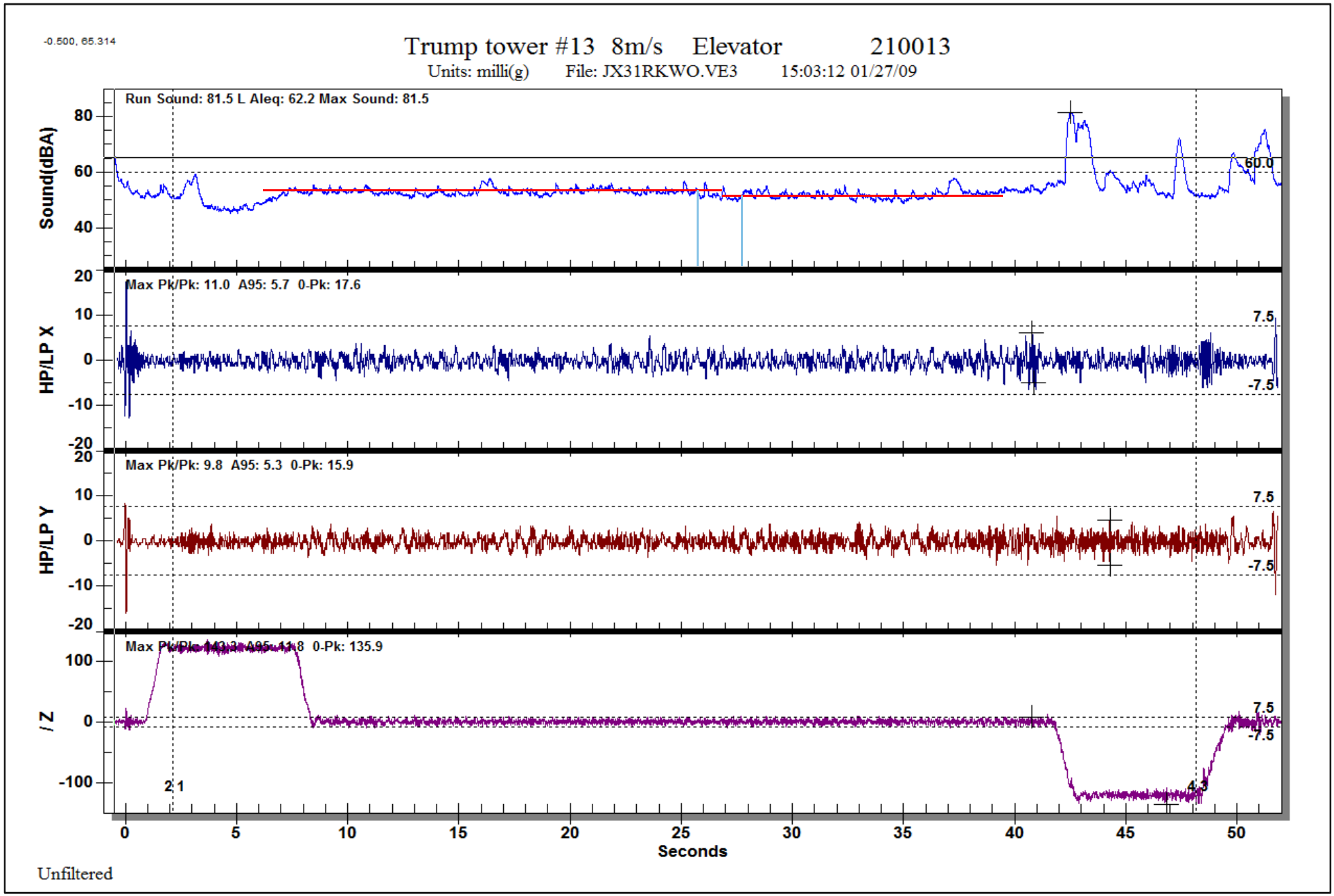


In order to prevent a shock-wave, similar to that of a train entering a tunnel at high speed, a transition wall is needed.

The length of the transition wall should be approx. the distance traveled by the elevator at full speed in three seconds.

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Tunnel Effect




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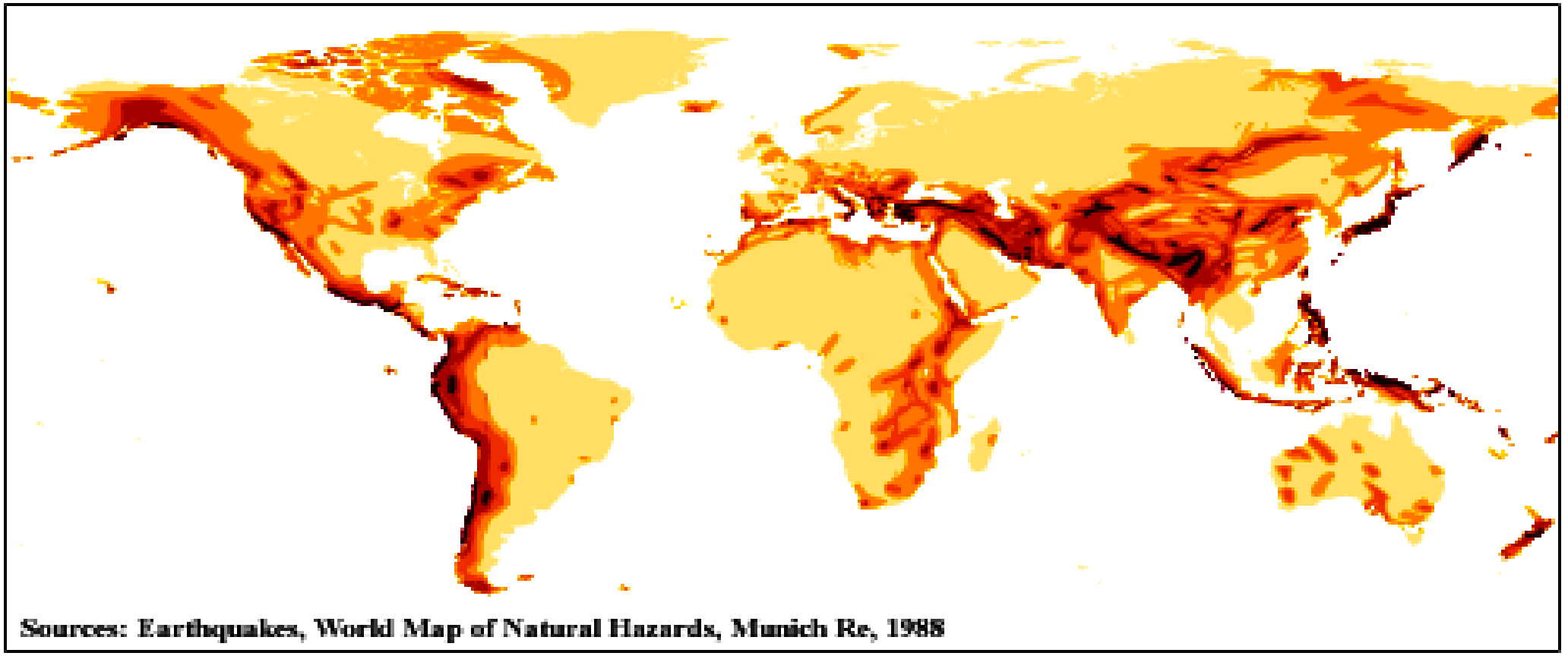
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KONE Earthquake protection

PROTECTING AGAINST DISASTERS

World Map of Natural Hazards, Earthquakes



Sources: Earthquakes, World Map of Natural Hazards, Munich Re, 1988

EARTHQUAKE INTENSITY SCALE (Modified Mercalli: MM)

"Probable maximum intensity with an exceedance probability of 20% in 50 years, for medium subsoil conditions"

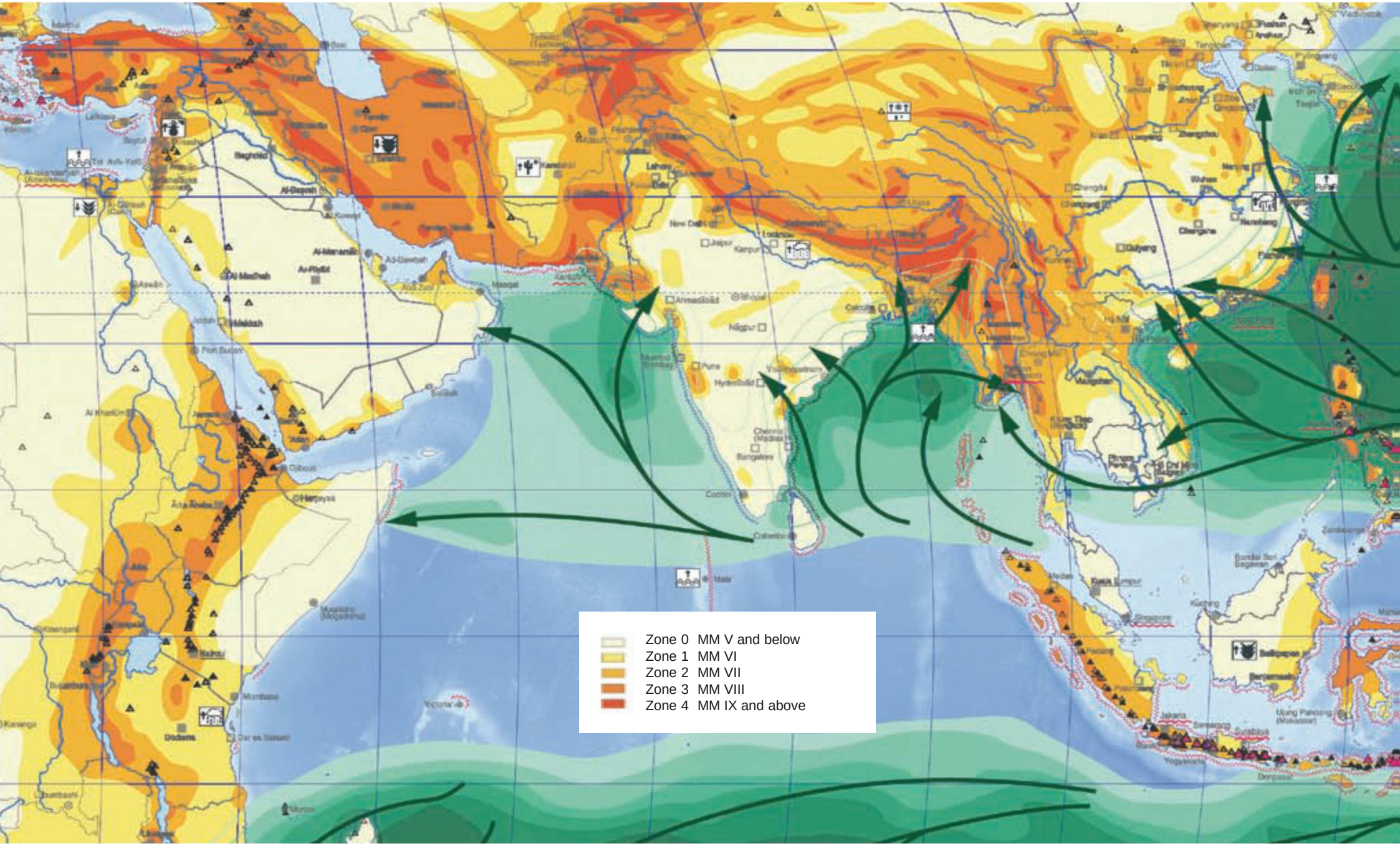
- Zone 0: MM V and below
- Zone 1: MM VI
- Zone 2: MM VII
- Zone 3: MM VIII
- Zone 4: MM IX and above

UNEP

EAD/GRID-Geneva

Earthquake map

Middle East and South East Asia



Construction method and Mercalli scale

BUILDING CATEGORIES IN SEISMIC ZONES

Construction method A
Structural work, building mortar and designs are of good quality. The building has been strengthened and is designed solidly against horizontal forces by using steel and concrete or something
else to bind the construction.

Construction method B
Structural work and building mortar are of good quality. The building has been strengthened but
not specifically against horizontal forces.

Construction method C
Structural work and building mortar are normal. There are no special weaknesses but the building has not been strengthened against horizontal forces.

Construction method D
Structural work, building mortar and designs are of poor quality. The building is weak in horizontal direction.

Building style	MM Intensity area						
	VI	VII	VIII	IX	X	XI	XII
A	-	1	5	20	50	80	100
B	-	5	20	50	80	100	100
C	1	10	40	80	100	100	100
D	5	20	70	100	100	100	100
Acceleration (g)		0,05-0,1	0,1-0,2	0,2-0,5	0,5-1	1-2	> 2

Table 1: Losses (%) expected every 50 year depending on the intensity area and the building style.

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Earthquakes and building height

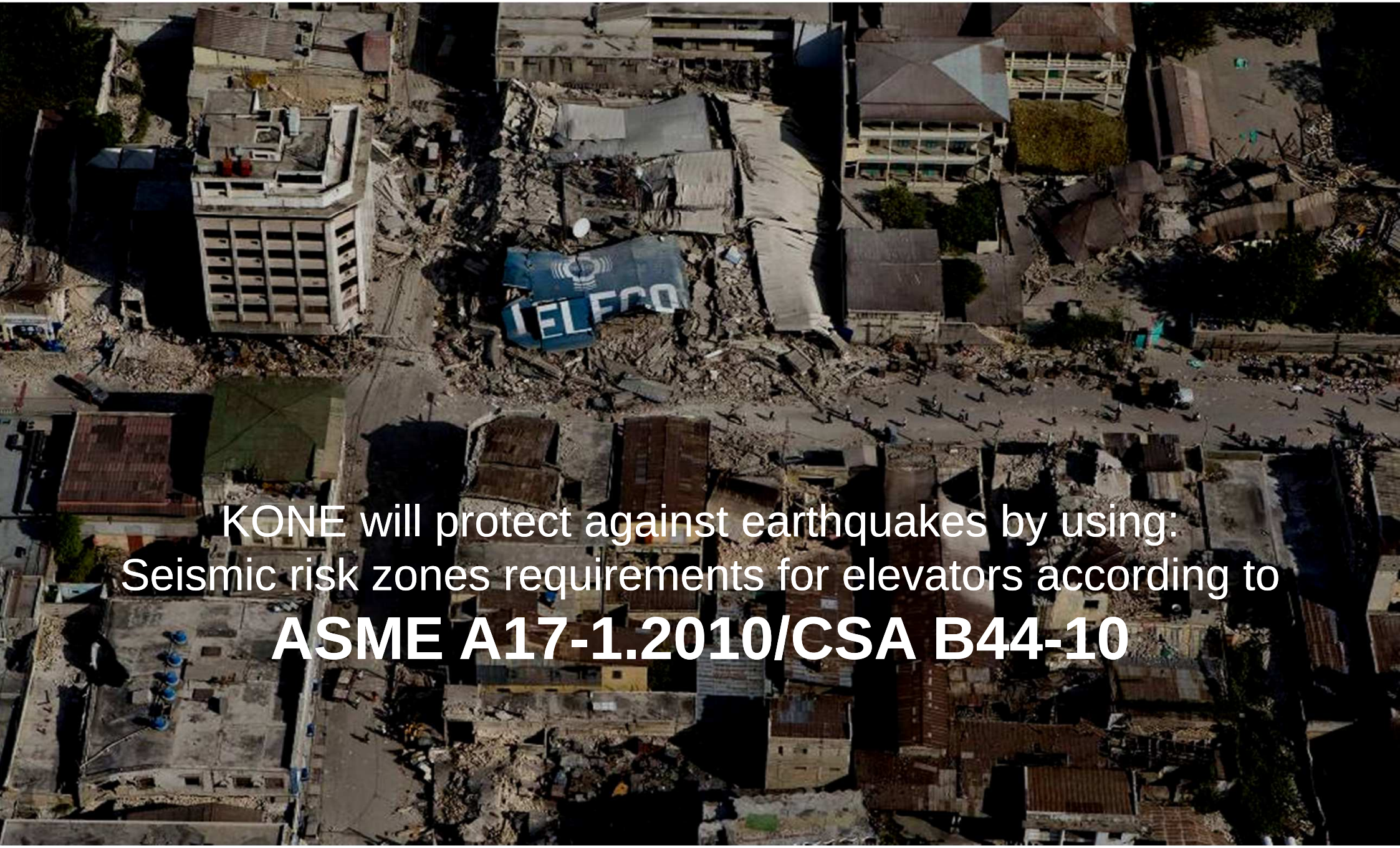


The following observations on the effects of earthquakes have been made:

- One to two floors building can collapse due to short and intense earthquake waves. These earthquakes do not always damage high buildings.

- Earthquake waves with a long cycle (> 1 s) can resonate with the undampened frequency of a high building (> 10 floors), which is very dangerous.

KONE Seismic zone requirements



KONE will protect against earthquakes by using:
Seismic risk zones requirements for elevators according to

ASME A17-1.2010/CSA B44-10


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