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Design a Suspended Access Equipment of Pakubuwono Spring Apartment

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Abstract

The Pakubuwono Spring Apartment built in Jakarta has a height of 170 meters which has façade glass and precast. So it's needed a tool for maintenance (cleaning and repairing) the apartment façade in the form of a Suspended Access Equipment or Building Maintenance unit (BMU). In this paper a Suspended Access Equipment will be designed that is suitable for those needs. The design was carried out using the EN 1808: 2015 standard. After that carried out research based on traversing, rotation, up and down and all positions BMU with simulation using AutoCAD Program, so that it is obtained the BMU Luffing type with outreach of 6,000 mm, mast height 1000 mm and has a cradle dimension of length 2500 mm x wide 600 mm x height 1000 mm with safe working load of 250 kg

Keyword: Suspended Access Equipment, Building Maintenance Unit (BMU), BMU Luffing type, Building Maintenance System, EN 1808 : 2015 Standard

I. INTRODUCTION

Suspended Access Equipment / BMU

Developments in major cities around the world are found in many skyscrapers with different architectural shapes and styles, either already completed or in the development process even in the design of which will be used as an office or place of residence. To maintain the condition of the building to keep it nice and beautiful, maintenance is needed on the façade of the building. More height and more complicated the shape of this building, the more difficult it will be to carry out maintenance, because of that it is necessary for the maintenance tool which is a Suspended Access Equipment that is popularly name of Building Maintenance Unit (BMU) or gondola.

Part of BMU which functions to raise and lower the cradle is a wire rope that is wrapped and rolled on a drum hoist and rotated using motorize with various safety equipment. Wire rope guides on the outside of the building using Head Jib. The head of the jib can be rotate adjusts to the position parallel to the façade, while the head jib is connected using Jib / arm adjusting the design and given counterweight. Jib, counterweight, head jib and cradle will be supported by the mast that stands on the trolley which will move to adjust the track position

In this paper the author will design a gondola for pakubuwono spring apartments that have a height of 170 meters, with an overall cleaning area of the façade that is an apartment building in the form of glass and precast, and other parts of the building, like the ceiling area of mechanical electrical floor, and wall of mechanical and electrical floor.

After doing various studies and simulations, the most suitable design is obtained with the design of this apartment building is a luffing type. The design was carried out using the EN 1808: 2015 standard.

II. LITERATURE REVIEW

The Suspended Access Equipment consists of 2 Categories [1]:

1. Permanent BMU
2. Temporary Suspended Platform

BMU categories base on power drive and mechanisme of hoisting consist of 2 type[1] :

1. Roof power BMU System , Wire ropes that suspend the cradle are wound in a multi-layered drum hoist. The drum hoist is housed in a roof car located at the roof top. In case of emergency, the drum hoist unit in the roof car could be manually released by the technician on the roof top, letting the cradle to descend to ground floor safely.
2. Self power BMU System, Wire ropes that suspend the cradle are wound in a multi-layered drum hoist with a maximum capacity of 160 m. The single or double hoist unit is/are housed in the cradle. In case of emergency, the hoist unit in the cradle could be manually released by the operator, letting the cradle to descend to ground floor safely

BMU category based on movement the trolley consists of 2 type [1,2]:

1. Trackless BMU, where this type uses wheels for movement on the roof the movement of the wheel is directed by steering and the maximum outreach is 7 meters
2. BMU with track rail, where this type uses track rail as a guide while BMU is run on the roof floor and for now it can be designed with a variety of models with a maximum outreach of 40 m.

BMU category based on the model or shape can be divided into [1,2,3,4,5]:

1. Fixed (Mast, Jib)
2. Telescopic, devided into Telescopic Jib, Telescopic Mast, or both (Jib and Mast) Telescopic
3. Luffing (Standard, and Z luffing)
4. Articulated

From of the various types based on technical, structural, aesthetic and cost considerations without reducing the function and purpose for manitenance and cleaning. The Concussion for Pakubuwono Spring apartment can be decided using the luffing model.

The method used in carrying out the BMU design is using a simple drawing technique that is using AutoCAD, by simulation of BMU drawing, that position and movement towards the architecture of building design.

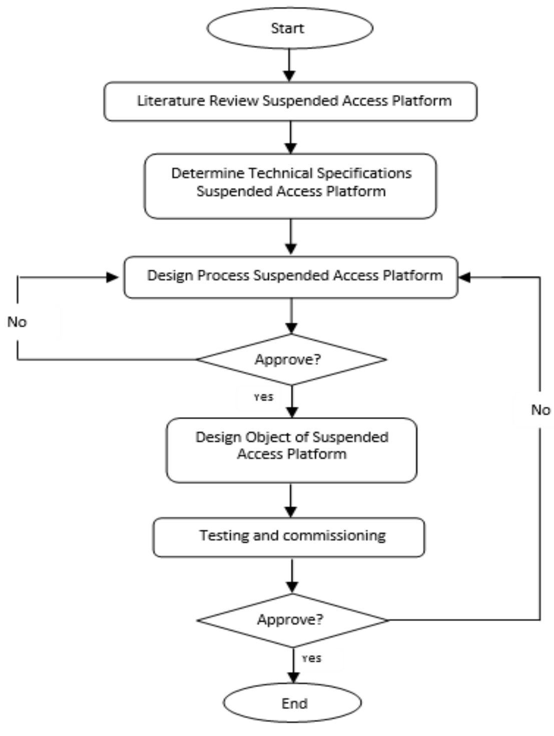
As reference design BMU for Pakubuwono Spring Apartment is BMU which has been installed in the Kompas Tower building, Neo Soho Podomoro City, WCT 3, and Caza Domaine Condominium which has BMU luffing types but has different dimensions and models.

This paper will explain the BMU luffing type design based on functional considerations, safety and architectural aesthetics, which are very highlighted in this Pakubuwono Spring Apartment[6,7,8].

III. METHODOLOGY

3.1. Design BMU

Flowcharts for the design of Suspended Access Equipment are as follows:



In designing BMU to clarify the idea of using the luffing model, it is done by making a simulation using AutoCAD, this simulation is detailed and includes the position of drop of cradle on parameters of building, things that must be considered in the design of BMU are as follows:

1. Outreach BMU is calculated from the BMU mast center to center of cradle
2. Height of BMU is calculated as base on height of parapet
3. Others of the mechanical electrical position at roof
4. Architectural of building models (building have recess, slope, arch, void, symmetric or many others models).
5. Restraint system, position level and layout[9]

Determining in load balance at BMU uses the basis of the balance of forces where the action force is the same as the reaction force, and counterweight is used to balance BMU

3.2 Clarity of the Function of BMU

Design desired for making a Suspended Access Equipment luffing type based on the design of the shape and function of the movement can be explained as follows[10,11]:

1. Traversing / Traveling: is the movement of Suspended Access Equipment needed to shift horizontally (left or right motion)
2. Lifting Motion: is the movement up and down the cradle which is pulled by a wire rope which is wrapped and rolled by a drum hoisting that is driven by a motor
3. Luffing motion / vertical rotation where this movement is a movement to bring the cradle of BMU closer or away from the facade area to be cleaned.
4. Motion Slewing Head: where this movement is a movement to align the cradle to ideal façade position

IV. RESULT AND DISCUSSION

4.1 Product Design Specification

The technical specifications for the Pakubuwono Spring Apartment project based on the provision issued by PT Meltech Indonesia as a mechanical electrical consultant and according to the outline can be described as follows. Guide line using EN 1808[9,12]

1. Covered all façade of building included plafond, and wall of roof mechanical electrical roof
2. Safe working load minimum 250 kg
3. Deadweight of BMU maximum 10 ton
4. Track gauge of BMU maximum 2000 mm
5. Roof power BMU as recommendation
6. Wire rope with copper conductor

4.2 Conceptual Design

No	Sub Function	I	II	III
1	**Cradle**			
	Dimension	3500x700x1000	2500x600x1000	2000x600x1000
	Material	Aluminium	Steel plate	Composite
	Model	Rectangle	Rectangle	Rectangle
2	**Trolley**			
	Height Mast	3000	2500	2000
	Length (Arm/Jib/Outreach)	7000	6000	5000
	Drive	Motorize	Manually	
	Hoisting Mechanism		Traction	Coiling
	Safety	Motor brake Blockstop Restraint	Motor brake Blockstop Restraint Limit switch	Restraint
	Gondola Type	Fixed Jib Fixed Mast	Telescopic Jib Telescopic Mast	Luffing
3	**Track Rail**			
	Material	Steel	Aluminium	Trackless
	Model	H beam	RS Extrude	I Beam
	Stumplate	400x400x12	300x300x10	350x350x11
	Anchor	M 16	M 20	M 25

From sub-functions 1, 2, 3, if will be combined a function as a whole so that the conceptual design of a tool to clean the building is usually called BMU (building maintenance unit) or often known as Suspended Access Platform or Gondola. Conceptual designs that can be arranged from a combination of 1 - 5 have many variations,

1. Selected of Cradle's variation:
   a. Dimension LxWxH 2500x600x1000 because it best matches the size of the width of 2 glass panels 2x 1200 mm and with the size of the width of the precast panel 3x 800mm
   b. Monologue type Aluminium material, best suited for light and strong material
   c. The general model is the rectangle type cradle
2. Selected Trolley Variations:
   a. Height mast: 2000 mm *
   b. Length of arm (outreach): 6000 mm *
   c. Motorize because BMU is very heavy estimate 8 tons
   d. Hoisting Mechanism: Coiling because coiling has more neat excess systems and wire ropes are not easily damaged
   e. BMU type: Luffing *

   **** Note:** base on simulation drawing with AutoCAD*
3. Variations in the chosen track
   a. Material Steel: Use Track Rail because BMU is very heavy estimate 8 tons
   b. Model H Beam: with the same dimensions of height and width will be stronger and stronger
   c. Stumplate: 300x300x10 will be chosen to save more material and costs while the technical is sufficient
   d. Anchor selected M16, based on the weight of BMU and the amount of H Beam 200 x 200 x 8 x 12 that is used is sufficient with that size

Based on the description, the resulting conceptual design is :

BMU Type Luffing, with cradle dimension 2500 mm x 600 mm x 1000 mm material aluminium model rectangle. Height mast 2000 mm, outreach 6000 mm with motorize drive using Coiling system with safety system Motor brake, Secondary Brake, restraint socket, and limit switch and for track using Steel type H beam with stumplate dimension 300x300x10 mm and anchor for pedestal type M16

4.3 Embodiment and Detail Design

Detail Process

The design of the Suspended Access Equipment form is the type of luffing that will be used for cleaning at the Pakubuwono Spring apartment facade. The considerations for using this type of luffing are based on functions for the entire area to be cleaned, namely the entire building façade, the mechanical electrical floor ceiling and the mechanical electrical inner wall of the pakubuwono apartment,

This Suspended Access Equipment design uses technical rules according to the rules EN 1808: 2015 which contain Safety Requirements for Suspended Access Equipment - Design calculation, Stability criteria, Construction - Ecxamination and Tests[9]. and this design is also based on building aesthetics that have been approved by Designer (Architect consultant) for elegance of building, and considering the structural loads that have been permitted by Structur consultant

Information Perspective design Suspended Access Equipment for pakubuwono spring apartment can so as follow :

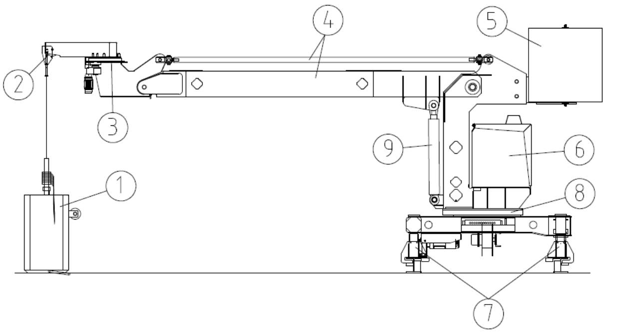


Figure 1. Design of a Suspended Access Equipment (drawn with AutoCAD)

Detail Information :
1. Platform (Cradle)
2. Head Roller
3. Platform slewing gear
4. Jib/Arm with Coupling rod
5. Counterweight
6. Hoist with box hoist
7. Traversing gear
8. Main component slewing system
9. Hydraulic for luffing system

Design BMU for pakubuwono spring apartment detail of BMU adjust Architectural building[13].

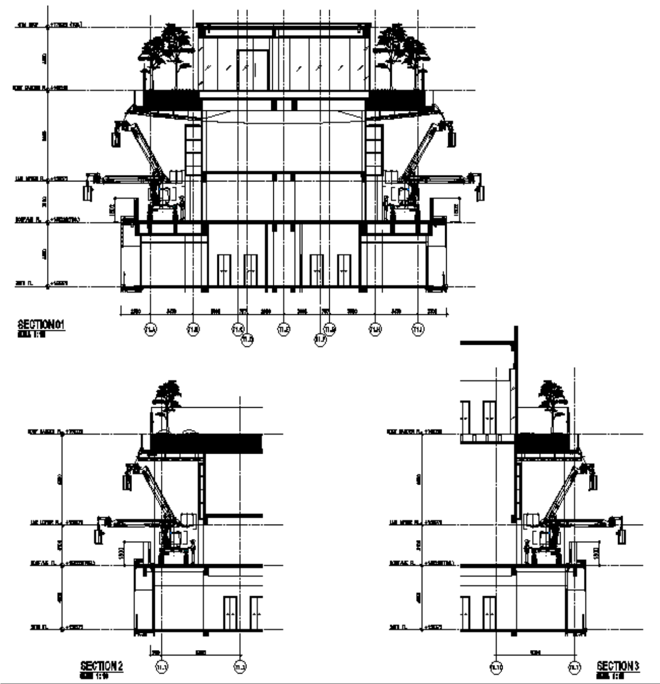


Figure 2. Simulation design
Suspended Access Equipment detail

After detailed design, including simulation of the entire façade of the building, the next step is the product manufacturing process, in this process will be explained briefly starting from the manufacture of mast and jib made of steel plate thickness of 12 mm to be rolled into blocks and welded so as not to stretch back. In the next process other parts of the gondola are assembled including trolley, mast,

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jib, cradle and driving mechanism (mechanical and electrical) until BMU forms are formed.

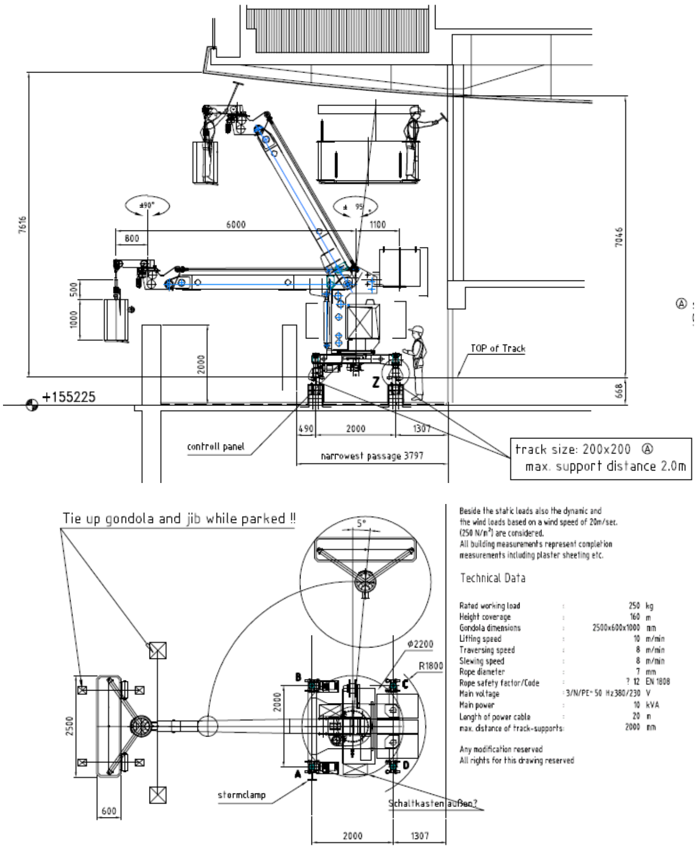
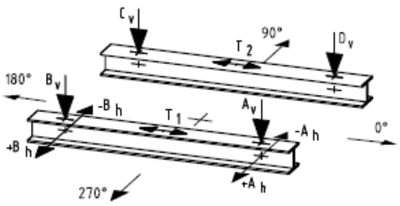


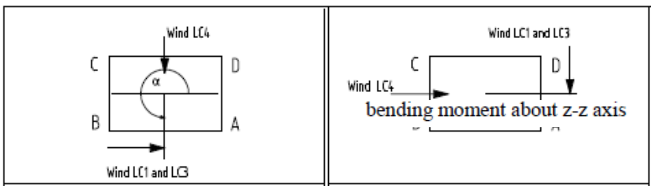
Figure 3.. Detail BMU cleaning position

Track Calculation



From design of the gondola the calculation of the load on the track has been obtained as follows :

Tolerance ± 15%



LC1;LC2LC4:α=270°					LC1;LC2LC4:α=0°				
	Tab 8			Tab 9		Tab 8			Tab 9
	LC1	LC2	LC3	LC4		LC1	LC2	LC3	LC4
	kN	kN	kN	kN		kN	kN	kN	kN
Av	34,4	27,7	-	38,3	Av	34,4	27,7	-	38,3
Ah	-5,6	0	-	1,7	Ah	7,7	0	-	0
Bv	30,4	28,5	-	39,0	Bv	17,1	10,1	-	2,4
Bh	5,6	0	-	1,7	Bh	-3,4	0	-	0
Cv	12,2	10,2	-	2,5	Cv	12,2	10,2	-	2,5
Dv	16,2	9,4	-	1,7	Dv	29,5	27,8	-	38,3
T1	9,3	8,0	-	10,5	T1	6,6	5,4	-	5,8
T2	0	0	-	0	T2	0	0	-	0
LC1	Σ A,B,C,D=1,25x(TSL+Mo+Mi+Fw1)				LC3	Σ A,B,C,D=Mo+Mi+Fw2			
LC2	Σ A,B,C,D=TSL+0,5xRL+Mo+MI				LC4	Σ A,B,C,D=2xTSL+1,25xMo+MI+1,25xFw1)			

Track calculation design will be check based on wheel load data on the rails[9]. with that wheel load will get a track rail size calculation that matches the gondola that has been made. After get the load wheel then entered into the formula for the reaction Values highest vertical and horizontal reaction, wherein the vertical reaction 38.3 kN and horizontal Reaction 7.7 kN

CODES / REFERENCES:

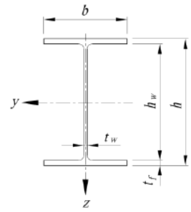
[1] EN 1808 : 2015 - SAFETY REQUIREMENTS FOR SUSPENDED ACCESS EQUIPMENT

W_v =	38,3	kN	max vertical wheel load
W_h =	7,4	kN	max horizontal wheel load
tol_w =	15	%	load tolerance
γ_f =	1,5		load factor
L =	2000	mm	distance between track support
Material =	SS400		specification of track material
f_y =	245	MPa	yield strength of track material
U_s =	400	MPa	ultimate strength of track material
E =	210	GPa	steel modulus of elasticity
G =	81	GPa	steel shear modulus of elasticity
g =	9,81	m/s^2	gravity acceleration

TrackSection = H 200 x 200 x 8 x 12

Track Section Properties:

m_{track} =	49,9	kg/m	mass per unit length
h =	200	mm	depth
b =	200	mm	width
t_w =	8	mm	web thickness
t_f =	12	mm	flange thickness
r =	13	mm	root radius
A =	63,53	cm^2	section area
I_y =	4720	cm^4	area moment of inertia y-y axis
I_z =	1600	cm^4	area moment of inertia z-z axis
$W_{y,el}$ =	471,6	cm^3	elastic section modulus y-y axis
$W_{z,el}$ =	160,2	cm^3	elastic section modulus z-z axis
r_y =	8,62	cm	radius of gyration y-y axis
r_z =	5,02	cm	radius of gyration z-z axis
I_t =	29,81	cm^4	torsional constant
I_w =	141000	cm^6	warping constant



$W_{z,elf} = (t_f * b^2) / 6$ flange elastic section modulus about y-y axis

$= 80{,}00\ cm^3$

$h_w = h - 2 * t_f$

$= 176{,}00\ mm$

$S_y = [(t_w * h_w / 2) * h_w / 4] + [(b * t_f) * (h_w + t_f) / 2]$

$= 256{,}58\ cm^3$ first moment of area about y-y axis

DESIGN LOADS:

$$W_{vt} = \gamma_f * W_v * (1 + tol_w)$$
$$= 66{,}07\ kN$$ vertical design load

$$W_{ht} = \gamma_f * W_h * (1 + tol_w)$$
$$= 12{,}77\ kN$$ horizontal design load

$$M_{y,Ed} = (W_{vt} * L / 4) + (\gamma_f * m_{track} * g * L^2 / 8)$$
$$= 33{,}40\ kN.m$$ bending moment about y-y axis

$$M_{z,Ed} = W_{ht} * L / 4$$
$$= 6{,}38\ kN.m$$

$$V_{z,Ed} = W_{vt} + (0.5 * m_{track} * g * L)$$ shear force
$$= 66{,}07\ kN$$ (wheel directly above one support)

YIELDING CHECK (EN 1808 ANNEX G.5.3) :

$$\sigma_{x,Ed} = (M_{y,Ed} / W_{y,el}) + (M_{z,Ed} / W_{z,el})$$
$$= 110{,}67\ MPa$$

$$(b * t_f) / (t_w * h_w) = 1{,}70$$

$$\tau_{Ed} = \begin{cases} V_{z,Ed} * S_y / (t_w * I_y) & \text{if } (b * t_f) / (t_w * h_w) < 0.6 \\ V_{z,Ed} / (t_w * h_w) & \text{if } (b * t_f) / (t_w * h_w) \geq 0.6 \end{cases}$$
$$= 46{,}92\ MPa$$

$$(\sigma_{x,Ed} / f_y)^2 + 3(\tau_{Ed} / f_y)^2 = 0{,}31$$ **OK (< 1)**

BUCKLING CHECK (EN 1808 ANNEX G.5.4.1) :

S = SQRT $[E*I_w / (G*I_t)]$
= 1,11 m

C_1 = 1,35 Table G.10
C_2 = 0,55 Table G.10
$C = \pi*C_1*[\text{SQRT}[1+(\pi*S/L)^2*(C_2^2+1)]+(\pi*S*C_2)/L]$
= 13,47

$M_{cr} = (C/L)*\text{SQRT}[E*I_z*G*I_t]$
= 1918,68 $kN.m$ critical buckling moment

$\lambda_{LT} = \text{SQRT}[f_y*W_{y,el}/M_{cr}]$
= 0,25

$\Phi_{LT} = 0.5*[1+0.49*(\lambda_{LT}-0.4)+0.75*\lambda_{LT}^2]$
= 0,48

f = 1

$\chi_{LT\_calc} = 1/(f*(\Phi_{LT}+\text{sqrt}[\Phi_{LT}^2-0.75*\lambda_{LT}^2]))$
= 1,09

$\chi_{LT} = \text{MIN}[\chi_{LT\_calc}, 1]$
= 1,00

$M_{b,Rd} = \chi_{LT}*f_y*W_{y,el}$
= 115,54 $kN.m$

$M_{y,Ed}/M_{b,Rd}$ = 0,29 **OK (< 1)**

CRUSHING OF WEB UNDER WHEEL CHECK (EN 1808 ANNEX G.5.4.3.a) :

$F_{z,Ed} = W_{vt}$
= 66,07 kN

$d = t_f + r$
= 25 mm

$\sigma_{z,Ed} = F_{z,Ed}/(2*t_w*d)$
= 165,17 MPa

$\tau_{l,Ed} = 0.2*\tau_{Ed}$
= 9,38 MPa

$(\sigma_{x,Ed}/f_y)^2+(\sigma_{z,Ed}/f_y)^2-(\sigma_{x,Ed}/f_y)*(\sigma_{z,Ed}/f_y)+3((\tau_{Ed}+\tau_{l,Ed})/f_y)^2$ = 0,51 **OK (< 1)**

DEFLECTION CHECK (per BS 5950-1 for Overhead Crane Girder)

$\delta_a = L/600$
= 3,33 mm

$\delta_{max} = [(W_v*(1+tol_w))*L^3/(48*E*I_y)] + [5*(m_{track}*g)*L^4/(384*E*I_y)]$
= 0,75 mm

δ_{max}/δ_a = 0,23 **OK (< 1)**

CRIPPLING OF WEB UNDER WHEEL CHECK (EN 1808 ANNEX G.5.4.3.b) :

$F_{z,Ed} = W_{vt}$
= 66,07 kN

For wheel load at a distance less than 1.5 times the depth of the cross section from the end of the beam:

$F_{z,Rd} = 0.125*t_w^2*\text{SQRT}(E*f_y)*\text{SQRT}(t_f/t_w)$
= 70,28 kN

$F_{z,Ed}/F_{z,Rd}$ = 0,94 **OK (< 1)**

BUCKLING OF WEB UNDER WHEEL CHECK (EN 1808 ANNEX G.5.4.3.c) :

$b_{eff} = h$
= 200 mm

$F_{z,Ed} = W_{vt}$
= 66,07 kN

$N_{c,Rd} = f_y*b_{eff}*t_w$
= 392 kN

$N_{cr} = \pi^2*E*b_{eff}*t_w^3/(12*h^2)$
= 442,51 kN

$\lambda = \text{SQRT}(N_{c,Rd}/N_{cr})$
= 0,94

$\Phi = 0.5*(1+0.49*(\lambda-0.2)+\lambda^2)$
= 1,12

$\chi = 1/(\Phi+\text{SQRT}(\Phi^2-\lambda^2))$
= 0,57

$\dfrac{F_{z,Ed}}{\chi*N_{c,Rd}}$ = 0,26 **OK (< 1)**

Restraint Socket

In accordance with the rules EN 1808: 2015 stated that restrain socket must be able holding 1kN force in all directions after being installed in facade in the form of either glass facade or precast or material facade others[1,9].

Figure 3. Restraint socket sample

In the design of safety to prevent accidents during the operation in which his name for safety equipment restraint socket where to images and vertical distances are as follows:

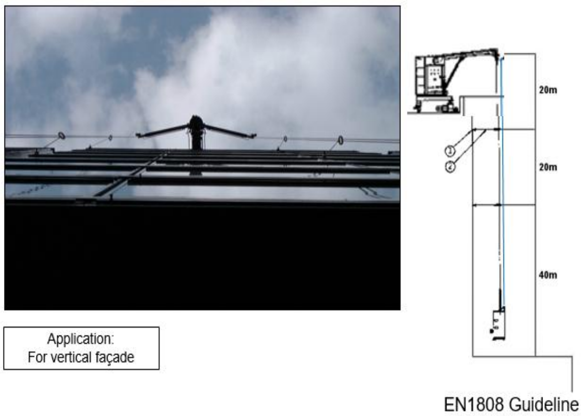


Figure 4. restraint socket vertical application

Based on EN 1808: 2015 about the installation of a restrain socket the distance between restraint above 40 m shall not exceed 20 m for vertical position.
How to calculate it is the point where the wire rope exits from the jib head, down to a maximum of 20 m, 20 m again until the lowest part of the building is calculated to be a maximum of 40 m from ground floor

Testing and Commissioning

Testing & commissioning is carried out after BMU has been installed in the Pakubuwono spring apartment attended by all relevant parties including owner, Consultant Architects, Consultant Mechanical & Electrical, Quantity surveyors, Management Construction and from Government represented by PJK3 officials from the labour department as the party that issued the BMU operating license certificate in Indonesia. and from the results of testing the commissioning, BMU for Pakubuwono Spring Apartments was declared feasible and allowed to operate

V. CONCLUSSION

The Suspended Access Equipment design carried out at the Pakubuwono Spring Apartment came to some conclusions:

1. The model that best fits the needs of the Architect, Civil Structure, Mechanical Electrical model, Facade is a Luffing model with a lift capacity of 250 kg with a cradle size of L x W x H (2500 x 600 x 1000) mm, with a mast height of 2000 mm and 6000 mm outreach using hydraulics for luffing drives
2. With simulations using AutoCad images, it can be seen that all the areas that you want to clean (Mechanical Electrical Floor ceilings, Mechanical Electrical Floor Walls, and the entire facade) can be affordable BMU
3. The standard used in this design is the standard EN 1808: 2015 which is used as guidance in safety requirements on Suspended Access Equipment (Suspended Access Equipment), design calculations, Stability Criteria, Construction - Testing
4. Safety from the operation of Suspended Access Equipment is determined using a Restraint Socket installed in the facade area made of glass or precast.
5. An operating permit certificate from the government that was represented by PJK3 Department, has been obtained as part of the Ministry of Labour who has the right to issue an operational permit certificate at the BMU

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Acknowledgements

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