A STUDY ON THE SUSTAINING CAPABILITY OF THE CURTAIN WALL SYSTEM FOR THE ATTACHED CLEANING ROBOT

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ABSTRACT: Recently, the curtain wall systems are widely used for the exterior walls of the buildings. In this regard, many studies on their cleaning and maintenance methods are being carried out. Now in order to review on the possibility of the attachment of the cleaning robot to the existing buildings, it is unavoidable for us to check the structural stability of the major members of the existing curtain walls.

From the preliminary reviews on the design documents and the shop drawings of the buildings, the constructed curtain wall is mainly made of aluminum and steel, which are categorized in to continuous beam, two-span continuous beam and simple beam according to the connected type of the curtain wall mullion members.

In conclusion, on the mullion of simple beam, the stress increasing ratio is proportionate to that of the robot load being attached. However, on the mullion of continuous beam, it is insignificant even with the robot load up to 20kN.

That is, the robot load within the limit of 20kN on the existing curtain walls shall be acceptable without further reinforcement being added.

***Keywords**: Cleaning Robot, Building, Wind Load, Curtain Wall, Mullion, Anchor*

1. INTRODUCTION

1.1 THE PURPOSE

Recently, the curtain wall systems are widely adopted for the exterior walls of most of mid-tier office buildings and the multi-purpose buildings thanks to their light weight and convenience in the construction.

So the studies have been carried out on the cleaning and maintenance of the walls by installing the manual, the semi-manual and the automatic robot systems.

Therefore, the study aims to review on the affordable weight to be borne by the curtain walls of the existing buildings in order to estimate the possibility of the application of the cleaning robots to them. That is, it aims to predict the maximum robot load to be attached to the wall by analyzing stress and displacement being caused on mullion and fastening anchors among the curtain members.

1.2 SCOPES AND METHODS

Among other exterior walls, this study focuses on the review of the bearing strength of structure of the exterior curtain wall which is considered as a weak structure and should be cleaned frequently.

The research methods employed are collection and analysis on a number of structural calculations and shop drawings of the curtain walls applied to the buildings. In succession, we zero in on structural system, standards of application, design loads, stress condition of the major members and deflection limits as the critical analysis items. Finally we cut out the weakest member of the curtain walls, based on which we predict the maximum cleaning robot load to be attached.

2. PRELIMINARY RESEARCH ON THE CURTAIN WALLS

2.1 TYPES OF CURTAIN WALL

The curtain walls are classified into Fig.1 according to materials, structural systems and construction methods.

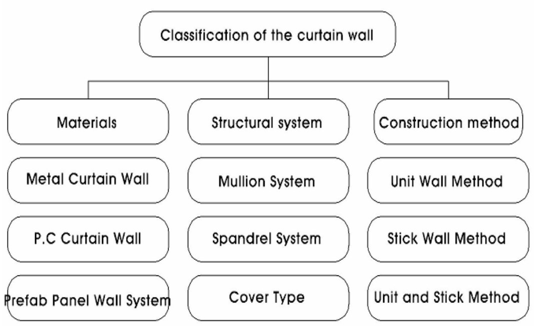

Fig.1 Classification of the curtain wall

Among other curtain walls, we select out mullion systems as the research objects. Because they are predominant in the markets.

2.2 CURTAIN WALL LOAD ANALYSIS

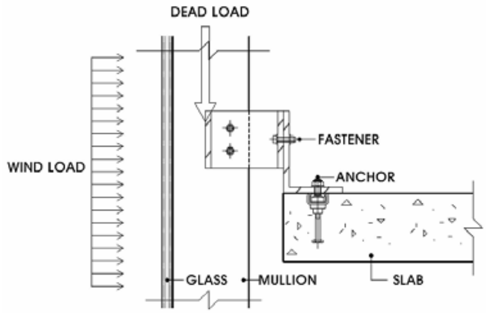

Fig.2 Curtain wall detail

The load on the curtain walls is as per the Fig.2, showing that it is flowing from dead load, wind load to glass, mullion, fastener anchor and slab or beam.

However, we consider mullion and anchor as main objects of the load analysis and exclude size and thickness(too diverse), brittleness material(too weak in terms of load resistance).

2.3 CURTAIN WALL DESIGN CRITERIA

We studied on the curtain walls base on the allowable stress design as per AAMA(American Aluminum Manufactures Associations) and AISC(American Institute of Steel Construction).

The design load is composed of dead load and wind load which are specified in Korean Building Code.

3. THE STRUCTURAL ANALYSIS ON THE CURTAIN WALL OF THE EXISTING BUILDINGS

3.1 CASE STUDIES

The cases which are selected by our study are as follows.

Purpose, height, material, design standards, structural analyzing programs are considered as criteria in the selection process.

Table.1 Case studies

Case	Purpose	Height	Material	Design standards	Structural analysis program
A	Multi-purpose building	161m	Aluminum	AAMA	Midas gen
B	School	96m	Aluminum	AAMA	Midas gen
C	Hospital	77m	Aluminum +(Steel Plate)*	AAMA ASD89	Midas gen
D	Government	46m	Aluminum +(Steel Plate)*	AAMA ASD89	Midas gen
E	Museum	19m	Steel	ASD89	Midas gen

(*:Further reinforcing material, Fig. 5 Reference)

Table.2 Design loads and members research results

Case	Zone*[1]	Dead load (kN/㎡)	Wind load (kN/㎡)		Mullion						Anchor		
			Positive pressure	Negative pressure	Connection type	w*[4] (㎜)	A (㎟)	I (㎜ 4)	Z (㎣)		Type	Distance (㎜)*[2] ar	vd
A	Typical	0.3	3.6	2.5	Simple beam	1,165.5	2,340	3,890,000	61,400		T-Head Bolt M16	90	190
	Corner		3.6	4.1	Simple beam	1,165.5	2,340	3,890,000	61,400		T-Head Bolt M16	90	190
B	Typical	0.3	2.1	2.2	Continuous beam	1,380	1,270	5,890,000	55,500		Set Anchor M12	75	40
	Corner		2.1	5.0	Continuous beam	1,390	1,270	5,890,000	55,500		Set Anchor M12	75	40
C	Typical	0.4	1.6	1.3	Continuous beam	1,240	1,480	8,060,000	70,700		T-Head Bolt M16	200	140
	Corner		1.6	3.0	Continuous beam	1,240	1,480 (474)*[3]	8,060,000 (2,760,000)*[3]	70,700 (7,650)*[3]		T-Head Bolt M16	200	140
D	Typical	0.45	1.1	0.9	Two-span continuous beam	1,300	1107 (676)*[3]	2,920,000 (1,270,000)*[3]	37,700 (21,000)*[3]		Set Anchor M12	80	35

	Corner		1.1	2.0	Two-span continuous beam	1,300	2,080	5,760,000	91,400	Set Anchor M12	80	35
E	Typical	0.50	1.7	1.4	Two-span continuous beam	2,200	9,380	54,180,000	481,700	Set Anchor M16	105	50
	Corner		1.7	1.6	Two-span continuous beam	2,040	9,380	54,180,000	481,700	Set Anchor M16	105	50

(*1: Fig. 3 Reference, *2:Fig. 6 Reference, *3: Further reinforcing material, *4:Fig. 7 Reference)

The results of the research on design load, mullion member connection type and section and anchor are as follows.

Design zone is divided into typical zone and corner zone by referring to wind pressure coefficients for the design of exterior wall materials of Korean Building Code.

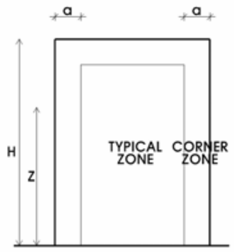

Fig.3 Design zone

Though, wind load is variable according to Table2, but the weakest data is applied to all curtain wall design zone and we assume that the same members are used for typical zone or corner zone in case of mullion and anchor.

The exterior of curtain wall is presumed as glass and we calculated the dead load by adding the self weight of glass and metal fitting.

In general, wind load is working as positive pressure to the front side of the buildings and negative pressure, to the rear. Therefore, the positive internal pressure increase causes the rear side pressure rise and the negative internal pressure increase, the front side pressure rise.

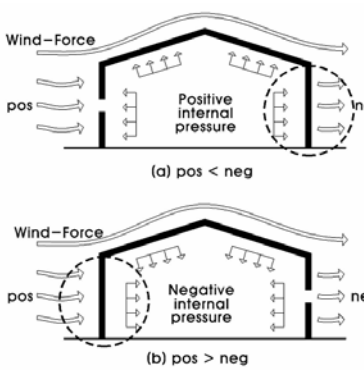

Fig. 4 Wind load according to internal pressure

Mullion members are structurally analyzed into continuous beam, two-span continuous beam and simple beam according to the connected type of the curtain wall mullion members.

In addition, most of curtain walls are made of aluminum material and according to Fig. 5 (b), the member stress shortage of aluminum section is reinforced by the steel plate.

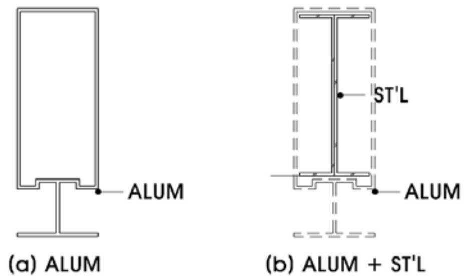

Fig.5 Mullion cross section

The anchors, supporting curtain walls and frames, are classified into T Head Bolt and Set Anchor which are mostly burial types as Fig.6.

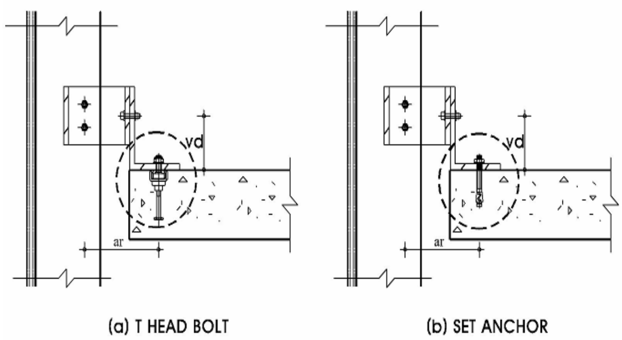

Fig.6 Anchor system

3.2 STRUCTURAL ANALYSIS ON CURTAIN WALL MEMBERS

The structural analysis of dead load and wind load on curtain walls is as per Table. 3.

Table.3 Structural analysis result of the members (%)

Case	Zone	Mullion stress ratio (actual stress /allowable stress)	Mullion deflection ratio (actual deflection/ allowable deflection)	Anchor stress ratio (actual stress/ allowable stress)
A	Typical	41	53	48
	Corner	46	60	54
B	Typical	67	30	40
	Corner	72	37	70
C	Typical	89	58	13
	Corner	87	50	60
D	Typical	36	30	25
	Corner	56	46	50
E	Typical	35	36	89
	Corner	32	33	77

The stress ratio of mullion members are construed to be ranged between 32~89% and the typical zone has the extra stress over corner zone because the same kinds of members are applied for the sections and the mullion members' interval to typical zone and corner zone are same regardless of design zone.

The mullion members deflection ratios are ranged between 30~60% and mullion member of the existing building are designed in consideration of stress rather than deflection as deflection ratio has more allowable of stress compared to the stress ratio of the mullion members.

Anchor is analyzed to have the stress ratio of 25~89%.

The stress of T Head Bolt is analyzed to have more allowance over Set Anchor because various anchor sizes such as M10, M12, M16, M20 are designed for set anchor according to reaction to loads. However, for T Head Bolt the minimum size, M16 only which has higher stress against reaction,

4. THE STRUCTURAL ANALYSIS WITH ROBOT LOAD

4.1 THE MOMENT AND REACTION CHANGES OF CURTAIN WALL LOADED WITH THE ROBOT

(1) Moment changes of the members caused by the robot

As Fig.7 shows, the self weight of cleaning robot causes torsion moment because cleaning robot is detached from the mullion members. So it causes bending moment, reaction and displacement on mullion members.

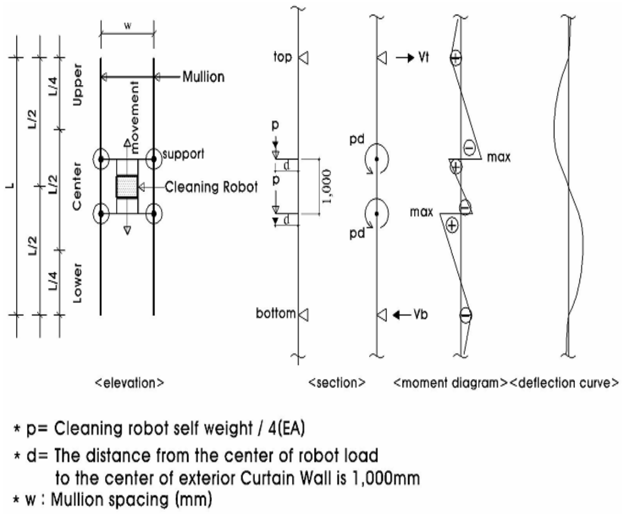

Fig.7 The moment and deflection by robot weight

(2) The moment by wind load

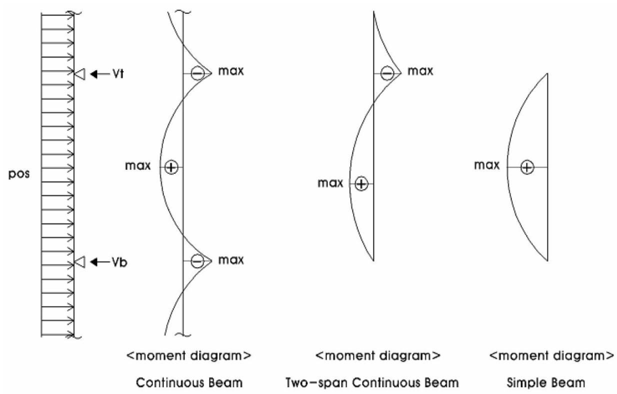

Fig.8 The moment by positive pressure

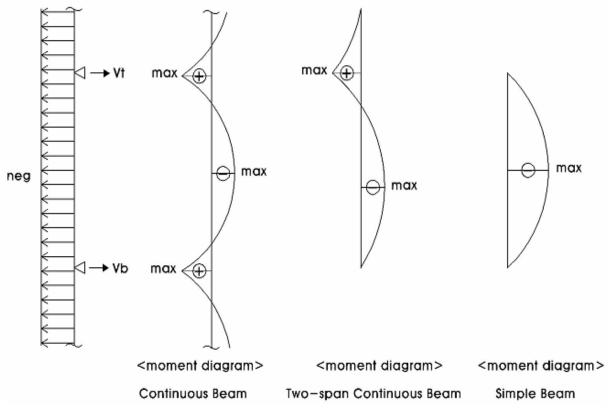

Fig.9 The moment by negative pressure

Table. 4 The moment and reaction change as per positions with combined load of robot and wind

Beam connection type	Wind pressure	By checking position moment and horizontal reaction				
		Mullion's moment			Anchor's horizontal reaction	
		Lower	Center	Upper	Bottom	Top
Continuous beam	pos	⇧	⇧	⇩	⇧	⇩
	neg	⇩	⇧	⇧	⇩	⇧
Two-span continuous beam	pos	-	⇧⇧	⇩	⇧	⇩
	neg	-	⇧⇧	⇧	⇩	⇧
Simple beam	pos	-	⇧⇧	-	⇧	⇩
	neg	-	⇧⇧	-	⇩	⇧

(⇧: increase, ⇩: decrease, ⇧⇧: significant increase)

(3) The combination of robot self weight and wind load

The moment and reaction changes according to the combined load of cleaning robot self weight and wind pressure are shown in Table 4.

As the result, if the maximum moment exists in the center part, the combination loads(robot load + wind load) increase the center part moment, regardless of positive or negative pressure.

However, if it exists in the edge part, the combination loads(robot load + positive pressure) increase the moment on the lower part of continuous beam and the combination loads(robot load + negative pressure) raise the moment on the upper part of continuous beam and two-span continuous beam.

Regarding anchor, regardless of beam types, positive pressure increases horizontal reaction on the lower part of it and negative pressure, on the upper part of it.

(4) The curtain wall member maximum stress according to checking position

Table. 5 The maximum stress according to position

Case	Zone	Beam analysis type	Wind pressure	Checking position	
				Mullion's stress	Anchor's horizontal reaction
A	Typical	Simple	Pos	Center	Bottom
	Corner	Simple	Neg	Center	Top
B	Typical	Continuous	Pos	Center	Bottom
	Corner	Continuous	Neg	Upper	Bottom
C	Typical	Continuous	Pos	Lower	Bottom
	Corner	Continuous	Neg	Lower	Bottom
D	Typical	Two-span continuous	Pos	Center	Bottom
	Corner	Two -span continuous	Neg	Upper	Bottom
E	Typical	Two -span continuous	Pos	Upper	Top
	Corner	Two -span continuous	pos	Upper	Top

We are able to predict the stress changes after cleaning robot being installed by comparing Table. 4 and Table.5 of the position causing the maximum stress in the curtain wall design of the existing building.

4.2 THE SURUCTURAL ANALYSIS ON THE CURTAIN WALL MEMBERS WITH ROBOT LOAD

(1) Mullion's stress ratio review

The below Fig.10 is showing the result of mullion member stress ratio caused by the cleaning robot self weight of 0~20kN and in the distance of 1.0m between the cleaning robot and the mullion member.

It shows that like A, D type, the members' central stresses increase with the robot load on the curtain wall, because the maximum stress occurs in the center. However, the stress increases in B, C, E type remain rather small because the maximum stress occurs in the edge part of continuous beam and two-span continuous beam, not in the center part where the additional robot load is borne and there is allowable stress.

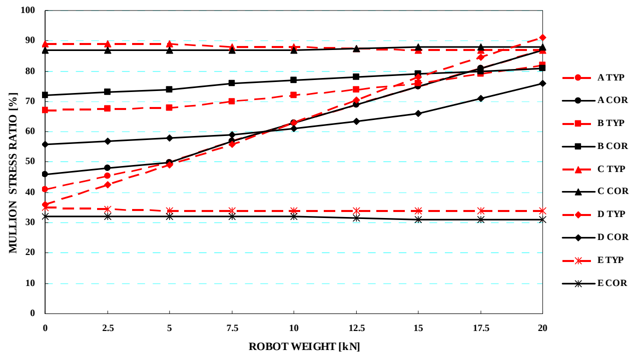

Fig.10 The correlation between robot self weight increase and mullion stress ratio

(2) Anchor's stress ratio review

The below Fig.11 is showing the result of anchor member stress ratio caused by cleaning robot self weight of 0~20kN and in the distance of 1.0m between the cleaning robot and the mullion member.

With cleaning robot load on, if wind load is positive pressure, the maximum stress occurs on the lower part anchor, if it being negative pressure, on the upper part of it. Fig.11 is showing that the stress ratio of anchor is increasing in A type, decreasing in B, C, D, E type corner and increasing slightly in B, C, D, E type typical.
Meanwhile, anchor stress ratio remains stable at 15% against robot load up to 20kN.

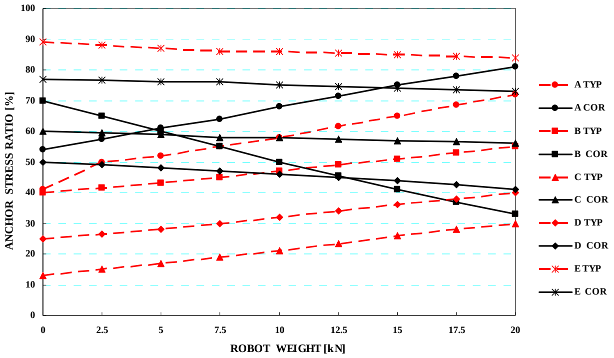

Fig.11 The correlation between robot self weight increase and anchor stress ratio

5. CONCLUSION

We have estimated the additional load (robot system) to be borne by the exterior curtain wall of the existing building by reviewing on the designing documents and the construction status judging from the point of the structural stability.

1) The constructed curtain wall is mainly made of aluminum and steel, which are categorized in to continuous beam, two-span continuous beam and simple beam according to the connected type of the curtain wall mullion members.

2) The mullion allowance is 10% and anchor allowance, 15% with cleaning robot self weight of 20kN, distance of 1.0m between curtain wall mullion center and cleaning robot center.

3) The mullion stress increase is insignificant with cleaning robot being loaded to the curtain wall of continuous beam and two-span continuous beam.

4) With cleaning robot load under 20kN, the anchor stress increases but it remains within the allowable stress.

Therefore, robot load is expected not to cause problems.

The cleaning robot attachment will be possibly borne by the existing curtain wall but the additional research on the attachment methods of the cleaning robot to the members and various exterior walls should follow shortly.

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