Case study of the weighed factors of stack effect and the reduction alternatives in tall complex building

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ABSTRACT

The purpose of this case study is to analyze stack effect problems and to develop the method minimizing stack effect in the tall complex building in the winter season. The main problems in tall complex building occur in high-rise elevators. Such problems in the elevator doors that do not close or exhaust air flows result in excessive pressure difference across elevator doors due to stack effect. Under the expected conditions causing the pressure difference, computer simulations with CONTAMW computer program and field measurement were performed in tall complex building. The results were analyzed by architectural design aspects. With those analyses, we suggest the tall complex building design guidelines to minimize stack effect.

1. INTRODUCTION

In most of tall complex buildings in the country, high-rise office building and low-rise commercial building on a large scale are connected at the lower floor in the building without any sections. In such case, the phenomenon to weigh stack effect of tall building by the shift of air that was flowed into low-rise building with frequent entrance and exit to tall office building. To solve the problems occurring due to such stack effect, certain interruption section of air stream at the joint part should be considered in advance at the planning stage of construction design if tall building is connected to commercial space on a large scale at lower floor. However, even in the tall building being constructed currently, the design is made without previous consideration about stack effect.
Hence, this study is aiming at proceeding the design review to stack effect from the design stage by selecting an tall complex building under construction recently as a case study, analyzing the weighed cause about stack effect from the design stage of the building

2. CONTENTS AND METHODOLOGY OF THE STUDY

2.1 Contents of the Study

"S" tall complex building selected as a case study is a typical tall complex building, in which office buildings with 40 floors and big complex commercial buildings with 10 floors are just connected from the 1st floor underground to the 10th above ground as shown in Fig. 1. Joint part between high-rise building and low-rise building is being opened frequently due to the flow of most of floating population moving like the dotted line shown in Fig. 1, then, air that was flowed into commercial building shifts to office building through connection path between two buildings.
Such shifted air stream rises on the elevator shaft for high-rise in the office building and flows out at high-rise in the office building. At that time, there is a high possibility to occur in problem at the elevator doors that are located at 10th floor, a joint part of commercial building and office building, and top floor of office building; the problems of malfunction of elevator door, noise, and air outflow. Besides, it is expected that there is a very high possibility to occur in the problems such as load disproportion between low-rise and high-rise, excessive air inflow, difficulty in opening/closing main doors, and the diffusion of smell, this study, therefore, searches for the analysis of the weighed cause to stack effect on tall complex building and the reduction method as below.

2.2 Research methodology

The progress of this study is as follows:
The basic design alternative of "S: tall complex building as an object building and investigation on the status of around the spot, and the weighed cause analysis of stack effect on the object building through questionnaire for similar case and the field measurement of the spot.
Executing CONTAMW computer simulation for prediction of airflow per the weighed condition of stack effect and pressure distribution, evaluation of stack effect of the object building in the winter season, and the presentation of primary stack effect reduction

alternative were done.

Executing the secondary simulation for the adopted alternative in the proposed stack effect reduction alternatives and for stack effect before/after the application of Zero Stack System, a stack pressure difference reduction system under developing; suggesting construction facilities/design guidelines of stack effect reduction for "S" tall complex forecasting building finally (executing the experiment per condition for the simulation verification at "G" tall complex building, a similar case).

Designing the weighed cause of stack effect on general tall complex building and suggesting facilities/design guidelines of stack effect reduction was done. The reduction alternatives of stack effect that was designed from this study was applied to the executed design of "S" tall complex building under construction currently, and the field measurement of the spot for stack effect reduction of this building will be performed after completion of the building.

3. SIMULATION OF THE BASIC DESIGN ALTERNATIVE AND THE SIMILAR CASE ANALYSIS

3.1 Review of the Basic Design Alternative and Simulation

The basic design alternative of "S" tall complex building has almost the similar shape of "G" tall complex building, a similar case as shown in Fig. 1. Low-rise commercial building and high-rise office building both are combined and it is expected that people in large numbers come and go to low-rise building with sales and complex cultural facilities through the connection paths to subway at the 1st floor underground. In the result of design analysis, it is expected that air stream in low-rise building would be flowed into high-rise building in large volume through the connection paths at the 2nd floor underground to the 10th over ground, and it is expected that the air inflow into parking place underground, ground floor connected to subway, and the 1st floor directly connected to outdoor air would be serious.

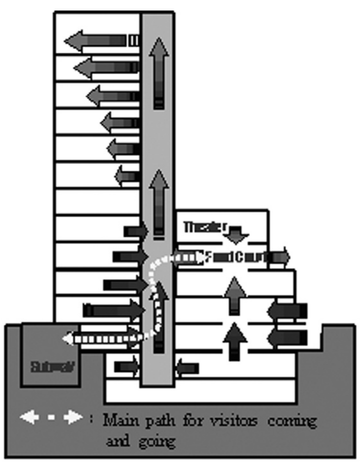


Figure 1: Expected airflow path in "S" tall complex building in the winter season

To evaluate the airflow and pressure distribution of "S" tall complex building in the winter season about the basis design alternative, CONTAMW program(1) was applied, which had been developed by NIST in the U.S.A. based on network model algorithm, and the reliability was admitted by having been applied to lots of studies until now. For simulation condition, -11.9 of air temperature, design temperature for the winter season, and 24 of indoor temperature were set, not considering the effect to wind in the outside by setting exterior wind velocity to 0m/s. In case of the elevators located at low-rise commercial buildings, all the pressure difference to the doors was shown less than 25Pa(2) in safety, which was the evaluation basis on stack effect for the simulation result of stack effect in the winter season as shown in Fig. 2, but in case of the elevators at tall office buildings, the values were much over 25Pa in most cases so it indicates that stack effect was serious. For reference, on the graph indication pressure difference in the elevator doors for office use in Fig. 2, the elevator is being planed to be operated from the 2nd floor underground to 1st floor over ground, 10th floor over ground, and 30th to 40th over ground, so pressure difference in odds floors was not indicated.

Furthermore, in case of emergency stairway room in the office building, pressure difference of doors in 1st floor underground to 5th floor over ground, 7th underground, and the roof exceeded 50Pa(3), the evaluation basis on stack effect to emergency stairway room.

Observing the pressure difference in the elevator doors for office use, seriously big pressure difference was indicated from the 2nd floor underground to the 1st over ground and the 10th over ground. It is the effect by air flowed from parking place in the 2nd floor underground, air flowed from subway connection path in the 1st floor underground, air flowed from entrance and exit doors directly connected to air; it is analyzed that the pressure difference from the elevator doors was largely risen due to inflow air stream from commercial building by frequently opening/closing of entrance and exit doors that were directly connected to commercial building in the 10th floor over ground. In case of occurring such pressure difference actually, there is a high possibility that malfunction occurs when the elevator doors are being operated. Even in high-rise over 35th over ground, the pressure difference over 25Pa was shown so it is predicted that air stream outflow and noise would occur when opening the elevator doors.

3.2 Similar case analysis

To analyze the weighed factor of stack effect in "S" tall complex building, we investigated the stack effect at "G" tall complex building, a most similar case building,

by interviewing the administrator of the building and the field work.
As drawn from the basic design analysis already, the air inflow volume at the 1st floor underground connected to subway in “G” tall complex building was serious so air inflow was being interrupted by installing several revolving doors at the connection paths. Main shift line of the floating population in this building is the shift line that is to be entered by the revolving doors at the 1st floor underground connected to subway and passed the hinged doors once, moved up to the 9th over ground by riding the elevator in office building at the 1st underground, and entered commercial building after being passed the doors between office building and commercial building once.

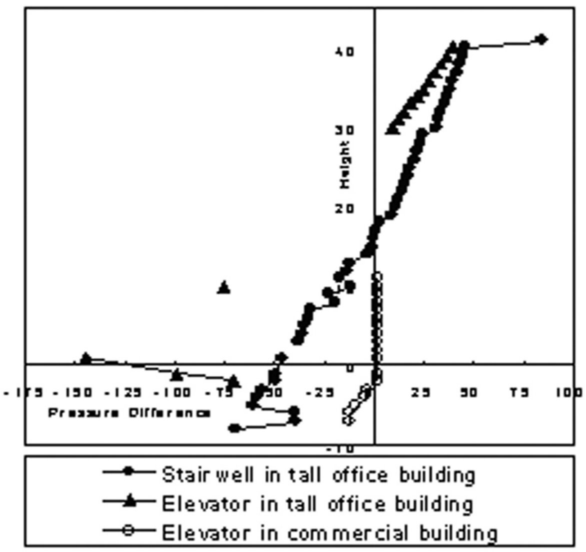


Figure 2: Pressure difference across critical doors

The reason why most of floating population occurs in this place is that multiplex is located at high-rise in commercial building; opening frequency of entrance and exit doors located at the shift line was too much due to the above reason, so air inflow into the elevator doors at the 1st floor underground and pressure difference rising and air stream inflow and pressure difference rising into the elevator doors at the 9th over ground were critical problems.
Furthermore, there are two escalator paths opened vertically in the commercial building of this building, so air in large volume that was flowed from the low-rise of this building rises up to the 9th, 10th floors and flowed into the office building. The critical issue in the problems due to stack effect occurring in this building was noise in upper floors at office building. Air stream that was flowed from lower part of the elevator in the office building exits from upper part of the elevator to indoor, then excessive air stream outflow and noise at gap occur so the people in the rooms complain the inconvenience.
Accordingly, the management of “G” building installed a vent in the control room at upper part of the elevator shaft to discharge the risen air stream and it results in great effect. A alternative in the stack effect reduction alternatives being applied at the spot was to open one of several elevator doors a bit not using intensively and to use it as an opening from which air stream of the elevator shaft can be flowed out for reducing the problems of excessive air stream outflow and noise in the other elevator doors being used in operation.
Such method was analyzed as a case that stack effect reduction alternative had been applied to the spot as very similar principle to the principle of pressure interruption system in the elevator door s that will be presented afterwards.

3.3 Presentation of the first alternative of stack effect reduction

The weighed factors of stack effect in the object building, which were drawn from the fieldwork of stack effect in the basic design alternative simulation about “S” tall complex building and the similar case building, and the subsequent reduction alternative are as follows:
First, low-rise commercial building and high-rise office building are connected as shown in Fig. 3 and the attraction policy of floating population on a large scale at top floor of commercial building is necessary. Hence, first of all, we suggest the alternative to reduce the people who enter and exit from the 1st floor underground to office building by installing the elevator to be used for multiplex only at the 1st floor of commercial building, which is connected to subway.
Second, we suggest the application of revolving doors with the most superior function of air stream interruption for cutting off airflow of the door for the entrance and exit doors at the 1st floor underground and lobby at the 1st over ground where have very big possibility of air inflow from lower floors of tall office building and for the entrance and exit doors of the joint part of office building and commercial building at the 10th floor over ground, where airflow is expected serious due to the entrance and exit peoples in commercial building and office building.
Third, since the floors in which excessive pressure difference occurs in the elevators at office building are the 2nd floor underground to the 1st over ground in low-rise in the building, the 10th over ground that is connected to commercial building, and the 35th to the 40th over ground in upper floors, we suggest applying Zero Stack System, a stack pressure difference reduction system under developing by our institute currently, to the elevator shaft. The field experiment for the evaluation of the pressure difference reduction system was executed

through the existing study (4).
Four, since the air stream risen from stack effect is flowed out through the elevator doors at upper floors of office building and noise with high frequency occurs, we suggest to install a vent that can discharge the risen air stream through the elevator shaft from elevator control room at top floor to settle the above problem.
For other matters, we propose applying anteroom at every entrance and exit doors in office building and commercial building and applying mohair, if movable for opening/closing direction, we also suggest settling the phenomenon of the doors being opened at all times due to pressure difference by air inflow interruption and stack effect, by planning the opening/closing available in the opposite direction against air inflow direction.

4. DESIGNING OF THE LAST ALTERNATIVES OF STACK EFFECT REDUCTION THROUGH SIMULATION AND THE SIMILAR CASE SPOT EXPERIMENT

4.1 Simulation and the similar case spot experiment

The stack effect reduction alternatives of "S" tall complex building, which were designed based on the basic design analysis and the field measurement results from the similar case building had been progressed for the spot experiment in the simulation and similar case in accordance with every condition possible to occur, and the very significant results per variable were shown in Table 1. Base case in Table 1 indicates the case of non-application of stack effect reduction alternative as the condition about basic design alternative.
Case 1 to Case1-C open indicates the condition by each stack effect reduction alternative. Case 1 indicates the case of installing revolving doors at entrance and exit doors connected to subway in the 1st floor underground, entrance and exit doors entered to the 1st underground in office building, and entrance and exit doors connected to the 10th floor in commercial building. Case 1-ZS indicates Zero Stack System operation in Case 1.
Case 1-A open indicates the case of door at A pint in Fig. 3 being opened and, Case 1-B open and Case 1-C open both indicate the same case.

Table 1: Simulation & Field Measurement conditions

Case No.	A (B1) Entrance /exit door connected to subway	B (B1) Entrance /exit door entering office	C (10F) Entrance /exit door connected to commercial building	ZS Pressure difference control system
Base				OFF
1	⊗	⊗	⊗	OFF
1-ZS	⊗	⊗	⊗	OFF
1-A Open		⊗	⊗	OFF
1-AB Open			⊗	OFF
1-C Open	⊗	⊗		OFF

4.2 The result of simulation and the similar spot experiment

The simulation results about stack effect reduction alternatives are shown in Fig. 4. In base case to show the basic design alternative in Fig. 4 (a), the pressure difference in the elevator doors shows too high totally, and in case of Case 1-ZS in which all the stack effect reduction alternatives were applied, it showed the minimum pressure difference and adopted for the final design alternative. In case of Case 1, Case 1-A open, and Case 1-AB open, the pressure difference at the 1st floor underground rises very much in the main entrance and exit doors (Fig. 3. B) at office building being opened together, while there is no change of pressure difference in the elevator doors in office building in case of the door (Fig. 3. A) connected to subway at the 1st floor underground being opened only; it is a result to indicate that the confidentiality of entrance and exit doors mostly adjacent to the lobby at office building is very important to reduce stack effect of tall office building. Case 1-C open indicates that in case connection door of commercial building and office building at the 10th floor over ground is opened, the airflow and pressure difference rise effect are very big and the confidentiality of this place (installation of revolving door, etc.) should be considered very importantly. Comparing the simulation result in Fig. 4 (a) to the spot experiment in the similar case in Fig. 4 (b), the absolute value is difference due to low basic temperature condition and the confidentiality of the spot but overall trend was same, it indicates that the simulation result is valid.

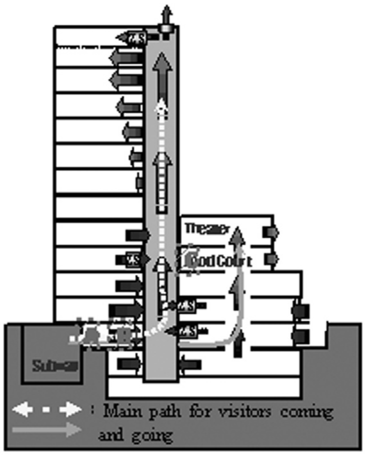
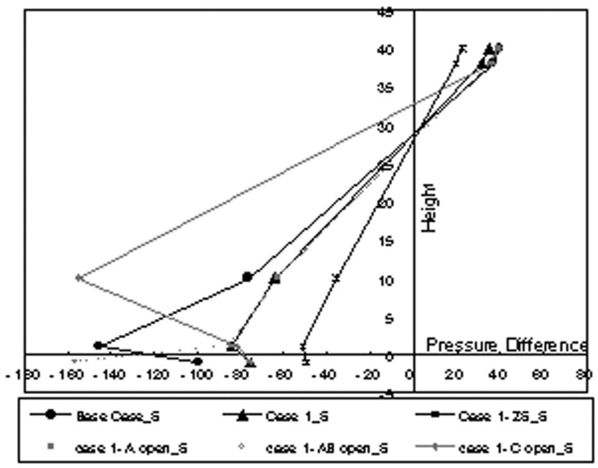
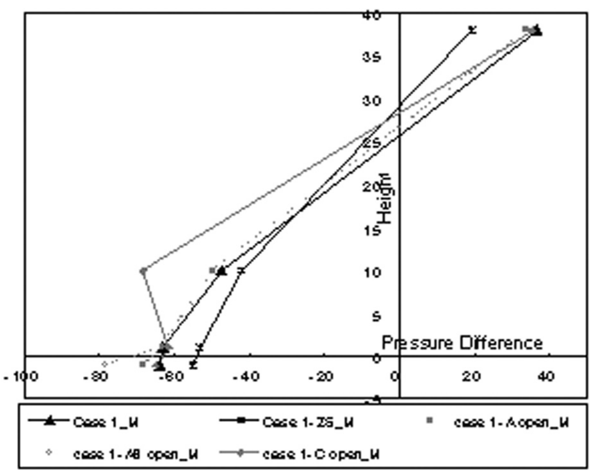


Figure 3: Expected airflow path in “S” tall complex building in the winter season under the conditions of stack effect reducing alternatives



(a) Result of simulations



(b) Result of field measurements

Figure 4: Pressure difference across elevator doors in the tall complex building

4.3 The last alternatives of stack effect reduction reflected on design

1) Applying revolving door to the entrance and exit door for connecting the 1st floor underground to subway and to the main entrance and exit door at the 1st floor underground in office building and to the main entrance and exit door at the 1st floor over ground in office building and to the connection door at 10th floor in commercial building/office building.

2) Applying anteroom to the connection door at the 1st floor in commercial building/ office building and to the connection door at the 8th to 12th floors in commercial/ office building and to the exterior connection door at the 14th floor in commercial building.

3) Applying Zero-Stack system to the elevator at high-rise in the building: Low-rise (the 1st floor underground, the 1st and the 10th over ground), High-rise (the 35th to the 40th floors over ground) and Installing damper for exhaust in the elevator control room.

4) Confidentiality of air inflow entrance and exit doors at the 2nd floor to the 5th underground.

- Installing Non-stop door in the opposite direction against air inflow direction and mohair at the gap of elevator door and the main entrance and exit door.

5. Conclusion and Discussion

The design guidelines of stack effect reduction of tall complex building, which were designed from the weighed factors about “S” tall complex building and the reduction alternative presentation, are as follows:

− *In case of tall complex building in which high-rise office building and low-rise commercial building are combined, high-rise office building muse secure the confidentiality of every door in office building and connection paths to the outside and the other building basically, in that case, the application of revolving door is the most effective but in case of not being settled by even the application of the revolving door, separate system application is necessary.*

− *Entrance and exit shift lines at low-rise in commercial building and those in office building must be separated; since air from frequent opening/closing of entrance and exit doors and air stream of commercial building are flowed into office building.*

FUTURE RESEARCH

The final alternatives of stack effect reduction that were designed from this study will be reflected on the performance design of “S” tall building, after completion of the building, stack effect reduction will be evaluated per alternative through spot experiment in the winter season, and verification study per alternative is scheduled to perform.

ACKNOWLEDGMENTS

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