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Development of a New Clean Demolition System for Tall Buildings

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Abstract

Manhattan, Chicago, and Tokyo are well known as skyscraper cities. But they have many decrepit buildings built in the early 20th century. It's a significant issue to renovate, retrofit or even demolish them. As one of the solutions, the authors have been developing a whole new demolition system for tall buildings. This system can contribute to a reduction of environmental pollution caused by noises or dust during demolition work because demolition and dismantling work is done in an enclosed space. Additionally, it is an important advantage that this system keeps open the possibility of reusing many elements. Several tall buildings in Tokyo were demolished by using this system. This paper reports enhancement of the system and some experiences gained from recent projects.

Keywords: Crane; Demolition; Dismantle; Enclosed; Jack-down

Introduction

The number of skyscrapers in the world has been steadily increasing for over a century. Among these, there are large quantities of decrepit buildings constructed in the early 20th century that have lost their property value. The question of what to do with tall buildings that are no longer useful is a critical issue we have been facing. It is clear that one of the best choices is to demolish them in order to accomplish the "resurgence of the skyscraper city" through construction of higher quality buildings. But, according to the database of the Council on Tall buildings and Urban Habitat (CTBUH), only 4 tall buildings taller than 150 meters have ever been purposefully demolished. In fact, very few systems address the demolition of tall buildings despite the fact that it will be more and more necessary in the future.

In the conventional demolition method in Japan, temporary scaffoldings and sound-proof panels are set up around the outer perimeter of the building. In this method, the top of the building remains uncovered while the crawler cranes and other heavy machinery, placed next to the building, are used to tear down the structure (see Figure 1).

With an uncovered top during demolition work, there are a number of concerns that present themselves, including increases in unworkable days due to inclement weather, scattering of

Figure 1. Conventional demolition method in Japan (Source: Taisei Corporation)

dust particles over wide areas, risk of falling debris, and generation of demolition noise and vibration. Furthermore, if the building is over 100 meters high, the wind at that height is expected to be about several times stronger than that of the ground, even in normal weather. This not only increases the hazard of setup, removal, and replacement of temporary materials (scaffoldings, sound-proof panels, and so forth), but also increases the costs of establishing safety measures. As demolition is carried out over long periods, it is essential to ensure the safety of neighboring people.

The TECOREP demolition system was developed with the implementation of three concepts: "Consideration for environment", "Safety", and "Conversion of energy". We conducted the demolition work on a 109-meter-tall office building in Tokyo to test this system.

However, this paper mainly covers the demolition of the 139-meter Old Grand Prince Hotel Akasaka in Tokyo – the second building to be demolished using this system. What is described in this paper can also contribute to the general knowledge base in the demolition field.

Overview of the TECOREP System

Concepts

The TECOREP system(Taisei ECOlogical REProduction system) is a brand new demolition method composed of three main concepts: environmentally-friendliness, safe demolition from the top floor, and conversion of energy. (see Figure 2)

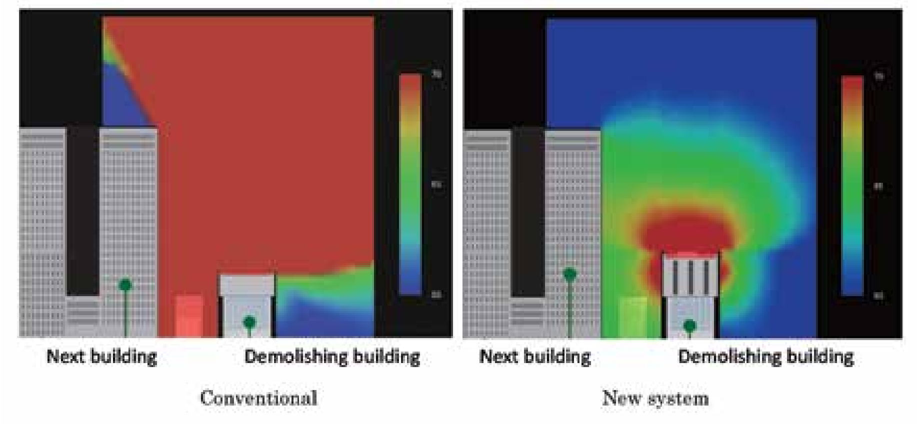

Figure 3. Noise Level Simulation (Source: Taisei Corporation)

The first concept, "environmentally-friendliness," improves upon issues related to the neighboring environment – such as noise or dust caused by the demolition work – by enclosing the entire demolition site. The structural frame of the existing building is used to build a roof above the top floor to enclose the space. Because it is unnecessary to construct a new frame for the roof, the amount of material needed to enclose the space is reduced.

The 2nd concept, "safe demolition from the top floor," is achieved through the development of a new demolition method. The enclosed rooftop "capping" is lowered after demolition work is completed on single- (or multi-) floor segments. This method avoids the need for scaffolding at dangerous altitudes.

The last concept, "conversion of energy," is achieved by developing a new electrical generating system. It is necessary for this demolition method, because taller buildings can produce larger amounts of power.

Figure 2. TECOREP system (Source: Taisei Corporation)

TAISEI, the company that developed this new demolition system, has already used mechanized construction technologies to build new buildings, including the use of the jack-system and ceiling traveling cranes. Some of these technologies and procedures are referenced in this development, and the technical knowledge and skill gained from that experience is utilized.

Noise Reduction

Conducting demolition work using the TECOREP system ensures high noise barrier performance because the work is completed within an enclosed space. When the level of noise caused by the system is compared to conventional demolition methods – in which the top roof is open – the former achieves noise reductions of about 20dB. (see Figure 3)

Prevention of Dust Dispersion

Dust dispersion can be greatly reduced by using the TECOREP system. Compared to conventional methods, this system generally inhibits about 90% of dust occurring during demolition. (see Figure 4)

Demolition procedure

In this system, part of top floor structure of the existing building is reused to create a "capping" mechanism. Safety is confirmed by the allowable stress design method. In order to ensure the sufficient structural strength and stiffness, some reinforcing elements are designed as the occasion demands.
Next, suspended protective scaffoldings are set up as surrounding walls. Ceiling traveling cranes and "telpher" cranes are set up in the capping for horizontal and vertical transportation respectively. The layout of

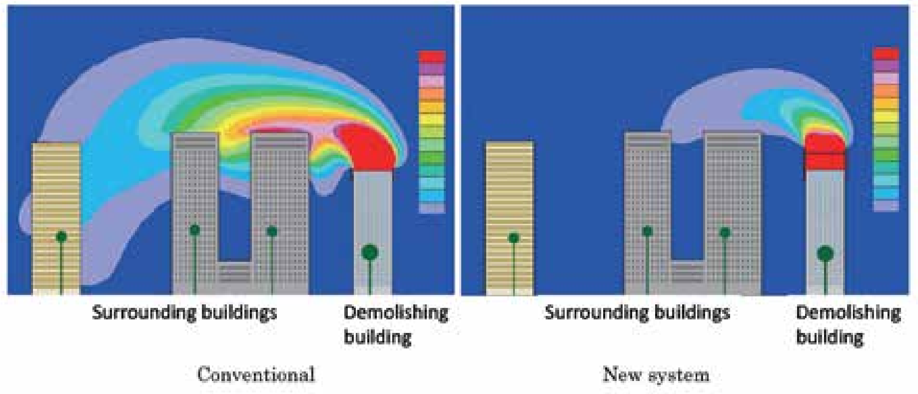

Figure 4. Dust dispersion simulation (Source: Taisei Corporation)

these cranes is determined considering the demolition procedure.

Temporary steel columns to uphold the capping and the hydraulic jacks for the jack-down procedure are set up at the perimeter zone of the enclosed space. The hydraulic jacks are installed on each of the temporary columns, and all of the jacks are linked to each other for increased control. The control room is located at the top roof; operators control each hydraulic jack and measure displacement and strain of each element indirectly.

After building up the capping, the second top-floor structure is demolished. As the last step to complete this system, the load of the capping is shifted from the existing columns to the temporary columns in a phased manner. Especially at higher levels of the building, the height can be different compared to the standard floor.

Primary jack-down is carried out and adjusted for the height of the capped section. Subsequently, the existing floors covered by this system are demolished, and the jack-down process is performed. The jack-down process is repeated until protective scaffoldings reach the ground. The demolition work is completed after removing scaffoldings or cranes. (see Figure 5)

Demolition of a Tall Building

Overview of the Old Grand Prince Hotel Akasaka

The Old Grand Prince Hotel Akasaka was a landmark located in the center of Tokyo. The hotel was a 39-story steel structure built in 1982. It had a total floor area of 67,750 square meters. The hotel had a typical story height of 3.2 meters, and typical grid spacing of 4 meters, which minimized the flexibility of the structure.

In the early 1990s "Bubble Economy" era, this hotel was one of the most successful in Japan. However, in the following years, investors opened more luxurious hotels in the area, which decreased the brand power of the Akasaka, and caused it to close in 2011. The owner of the hotel considered the locational environment of the building, and ordered TAISEI to demolish the building. This hotel was the tallest building to be demolished in the history of Japan, so it was indispensable to ensure safety. In addition, taking environmental care of its surroundings was required since the building was built in the dense inner city. As a result, the TECOREP system, which TAISEI developed, was adopted. (see Figure 6)

Demolition program

In order to secure a large space for the demolition work, girders for the capping floor needed high stiffness. But in the hotel, the stiffness of the existing girders was not high enough. Hence, a truss structure was built utilizing existing columns and girders of the top two floors and additional lattice bracing. Then, the outer scaffoldings were placed by hanging them from the steel structure of the roof, covering three floors. The top two floors covered by the scaffolding were demolished first. By leaving the lowest of the covered floors un-demolished, a safety area was created. The 15 temporary columns which upheld the capping were located at the perimeter zone of the buildings in a balanced manner.. (see Figure 7)

Verification of Noise Reduction

In this demolition system, noise barrier performance is improved by setting sound proof panels around the external scaffoldings. The effect of the noise barrier performance of the new system was compared to that of the conventional method, and it was confirmed

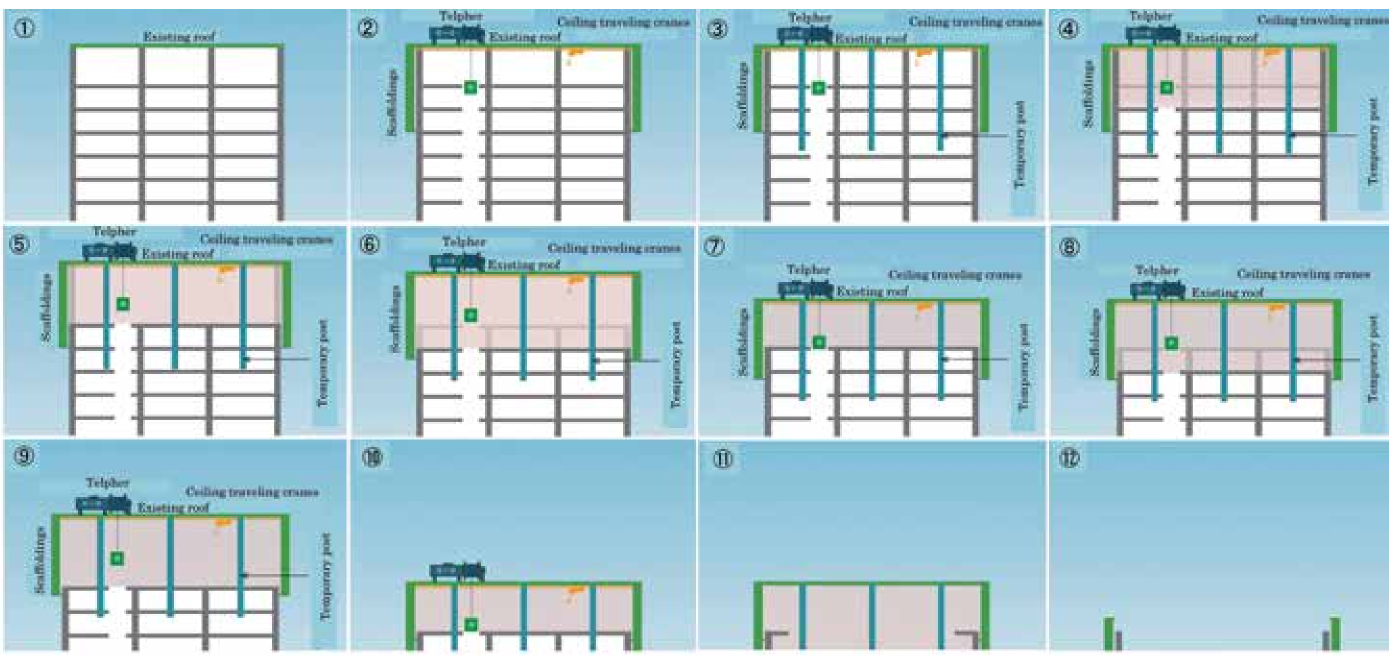

Figure 5. Demolition procedure by TECOREP system (Source: Taisei Corporation)

Figure 6. The Old Grand Prince Hotel Akasaka (Source: Taisei Corporation)

that 20 dB of noise could be reduced. By adopting the system, the noise level became similar to the traffic noise of Tokyo. As an additional test, noise level was measured with double sound proof panels. Compared to the scaffoldings with single-side sound proof panels, scaffoldings with both side panels achieved additional noise reductions of 10dB. (see Figure 8)

Verification of Dust Dispersion

It was verified analytically that the dust dispersion could be prevented in case the demolition work was done in the capped section. In case of this hotel demolition, the dust amount survey was made and the effect of reduction of dust dispersion was confirmed actually. One full cycle of the demolition work (one jack down, demolish two floors) was defined as unit time period, and the survey was implemented three times. As the result, it was confirmed that the capped section catch 80% of dust occurred from demolition work. Although noise and dust problem inevitably come with conventional method, the TECOREP system can be free from such problems and has an innovative advantage. (see Figure 8)

Verification of safety

In order to ensure the safety of the demolition work, three kinds of verifications were performed; the reaction force of temporary columns, the adequacy of seismic design force, and the measurement for wind load were all recorded.

In the TECOREP system, it is important to predict the value of the axial force of each of

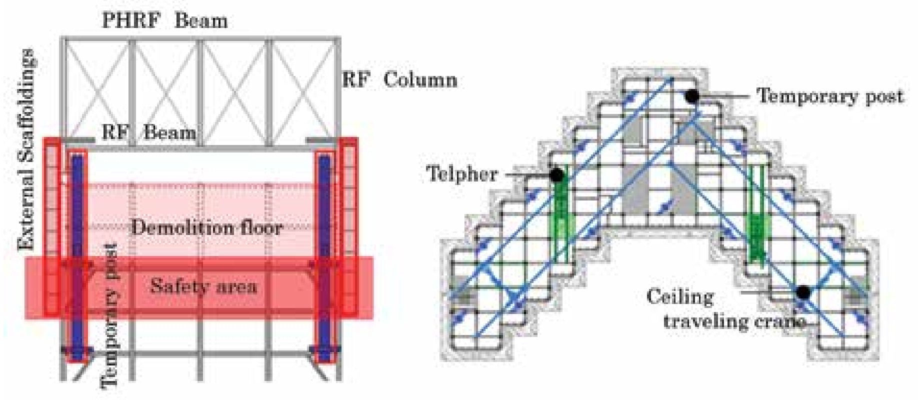

Figure 7. Demolition program (Source: Taisei Corporation)

the temporary columns in order to ensure the safety of the demolition work and the neighborhood. Columns were designed and located every 4 meters to satisfy both the high seismic performance and design in the hotel. In order to create a large space for demolition, some of the existing columns were cut off sequentially, so temporary columns were designed at the perimeter zone to uphold the weight of the capping instead of existing columns. First, after creating the truss structure of the capping, the 38 existing internal columns were cut off. Then, each of the external columns were separated in four groups and cut off sequentially in a balanced manner. In this procedure, 80% of the expected axial load was input into the temporary columns, aiming to deduce the varying axial force. Measured and analyzed values of the reaction forces were almost the same; the difference of each column was generally less than 10%. The difference of the whole weight of the capping is 19 tons (1,507 tons were measured during analysis and 1,526 tons were measured from actual demolition). The analysis was extremely precise and the demolition work was done safely. (see Figure 9)

Highly relevant to this project is the fact that this demolition work was done in Japan, which is located in one of the highest seismic risk areas in the world. It is necessary to ensure safety against an earthquake, which could happen during the demolition work, or at worst, during the jack-down procedure. In this project, the safety of the TECOREP System in combination with the existing building has been analytically examined. Before designing this system, two kinds of seismic forces were

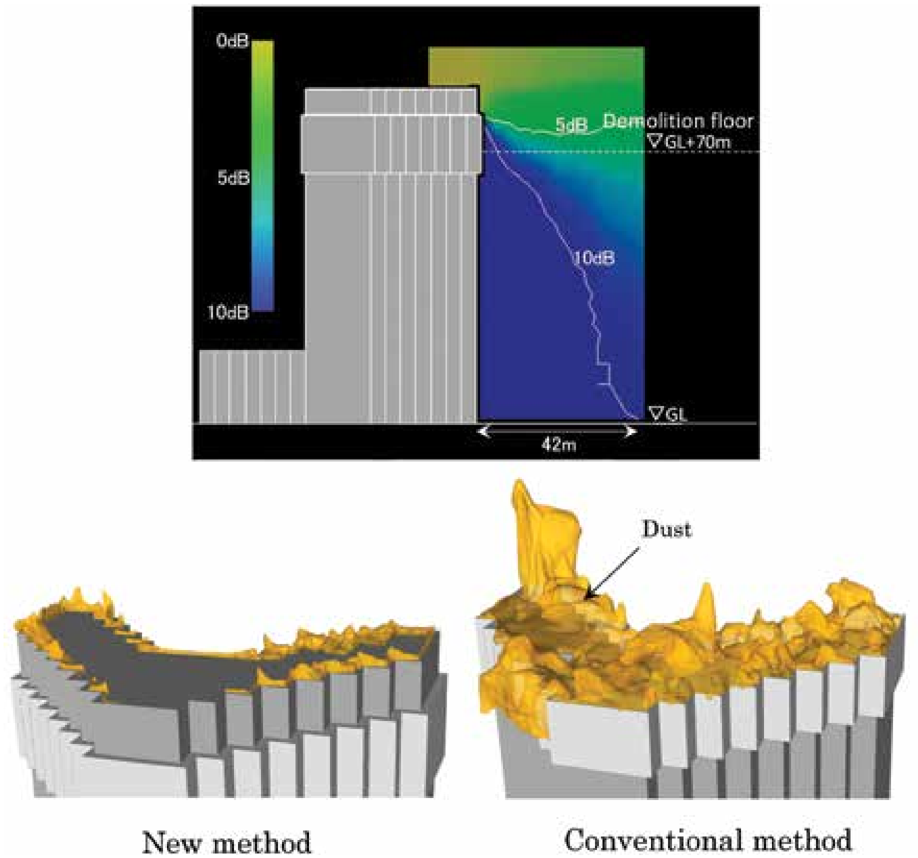

Figure 8. Reduction of environmental load (Source: Taisei Corporation)

defined; 0.2W (W: the weight of the structure) for small-to-midsized earthquakes and 0.5W for major earthquakes. In this paper, small-to-midsized and major earthquakes are referred to as "level 1" and "level 2" respectively. Against these force levels, design criteria were defined during demolition work and jack-down phases. In order to verify the appropriateness of the loading condition, a time-history analysis was performed. For "level 1" earthquakes, artificial design waves defined in Japanese code were used. For "level 2" earthquakes, two types of major earthquakes – Tokai and Tonankai Consolidated Type Scenario as a long-period earthquake and North Tokyo Bay Scenario as an epicentral earthquake – were used. Since the number of stories change in series as the demolition work proceeds, four kinds of analysis models were prepared: a 36-story model, 29 story-model, 19-story model, and nine-story model. (see Table 1) The 3D frame models were used to design the TECOREP capping. The whole building, including the system, was modeled as a lumped mass, and the material nonlinearity was considered by the skeleton curve gained from the static and elastic plastic incremental analysis. (see Figure 10)

Fig. 12 shows the maximum response of the story drift angle, shear force, and shear coefficient. Against "level 1", the maximum response of the shear coefficient at the capped section was 0.20 and the maximum response of story drift angle was 1/256; both results satisfied the design criteria. 0.44 as the maximum value of the shear coefficient, and 1/104 as the maximum value of story drift angle were gained for "level 2" long-period models. In regard to the "level 2" epicentral earthquake, 0.49 and 1/61 were gained respectively. 1/61, which is the response at TECOREP capping, is considered relatively large as a response for "level 2." But the temporary columns of the capping were deeply threaded into the building rigidly; therefore it was concluded the possibility of the collapse of the capping was low. As a result, against the two kinds of major earthquakes expected, the appropriateness of the design criteria was confirmed. (see Figure 11)

Whereas earthquakes occur with no warning, the possibility of a typhoon can be predicted thanks to the weather forecast. Thus, the measure against typhoons is planned by adding some temporary bracing elements according to the level of the typhoon.

Regenerating utilizing unloading process

The motor installed in the vertical transport system (telpher cranes) needs electricity in

	earthquake load during demolition work		earthquake load during jack-down phases	
	level 1	level 2	level 1	level 2
Loading condition	"shear coefficient 0.2"	"shear coefficient 0.5"	"shear coefficient 0.2"	"shear coefficient 0.5"
design criteria	whithin allowable stress SDA whithin 1/100	not collapse	"not plasticized severely"	not collapse

Table 1. Design criteria (Source: Taisei Corporation)

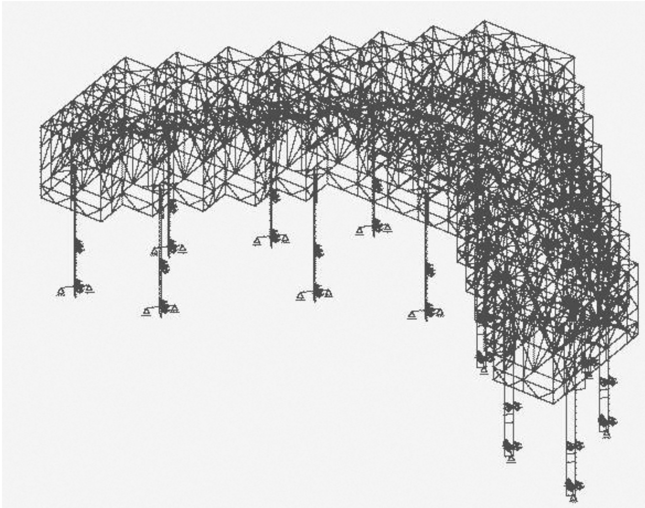

Figure 10. Analysis model of capping (Source: Taisei Corporation)

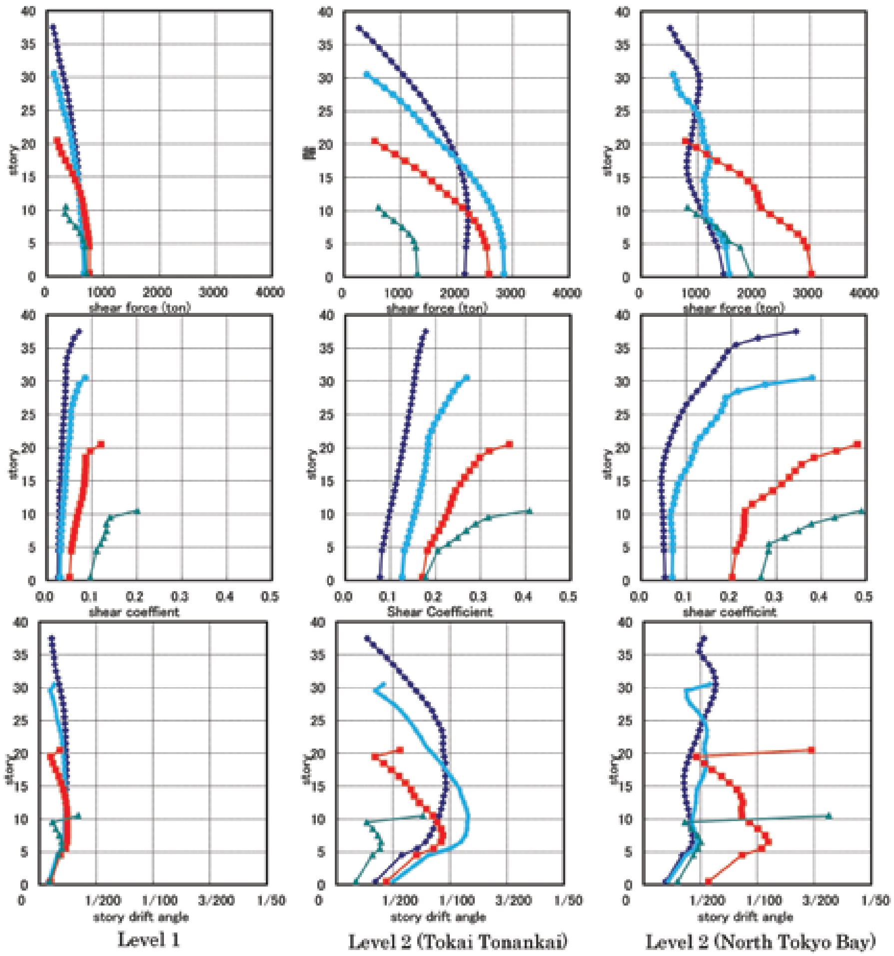

Figure 11. Extract Result of analysis (Source: Taisei Corporation)

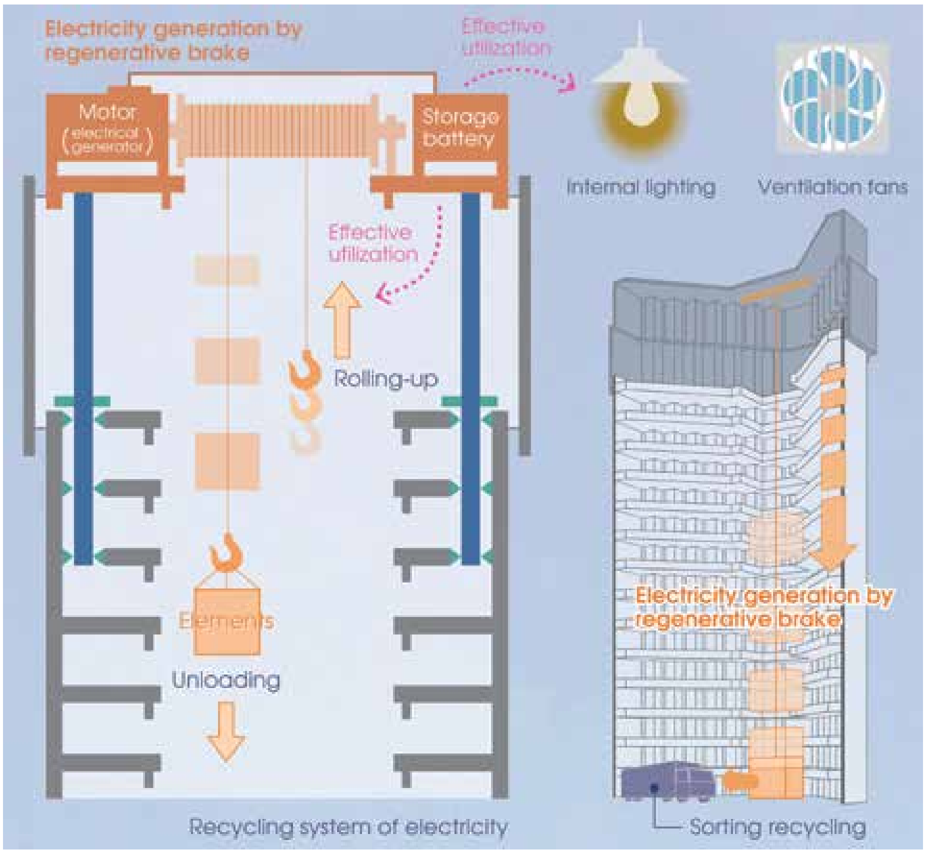

Figure 12. The electricity regeneration using "telpher" cranes (Source: Taisei Corporation)

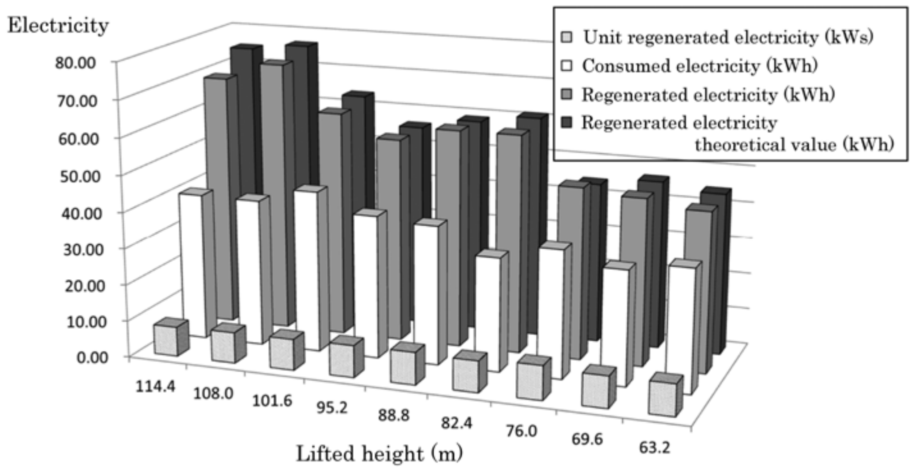

Figure 13. The electricity regeneration using "telpher" cranes (Source: Taisei Corporation)


Figure 14. Work proceeding situation (Source: Taisei Corporation)

hoisting phases and regenerates by operating as the electrical dynamo in unloading phases. In this demolition project, electricity was charged in a storage battery and reused in hoisting phases. Regenerated and consumed electricity were measured during lifting activity. (see Figure 12)

From 63.2 meters to 114.4 meters, the regenerated electricity exceeded the consumed electricity. The average amount of weight that the telpher cranes unloaded at each floor was 199.1 tons. The ratio of the regenerated electricity to consumed electricity was 155.9%. In order to analyze the detail of electricity efficiency, the "unit generated electricity" was recorded. It indicates the generated electricity that is gained when elements with 1ton is unloaded by 1m, and the value was almost constant regardless of story height. It is a useful conclusion that electrical power generated during the demolition work can be predicted easily. Also, it can be concluded that ecological demolition work was completed by adopting such regeneration system. (see Figure 13)

Cost Performance

The wind load level at the top floor of the hotel was expected to be higher than that of the 1st project due to its increased height. But, demolition work was done safely since it was completed in an enclosed space. There are, of course, multiple methods of conventional demolition work for tall buildings. One comprises building up the temporary scaffoldings from the ground level to the top of the building by reinforcing them with high stiffness elements. Another is that temporary scaffoldings are built on supports which are installed at the middle level of the building. In any case, construction of the scaffoldings is expected to be dangerous work. And after the demotion work of each floor is completed, workers have to disassemble the scaffoldings. All of this work means that it will cost more money than the TECOREP system. This is a big advantage for the system. In the hotel demolition, one cycle of jack-down was carried out after demolishing two floors in order to reduce the overall demolition period. It takes 4 hours for one cycle of the jack-down process, including the preparation work. The number of jack-down processes was halved with the two-story jack-down method, and the demolition period was reduced as a result. In the future, more cost efficient demolition work will be possible if yet-more multi story jack-down methods are developed. (see Figure 14)

Figure 15. The utilization of the existing roof structure (Source: Taisei Corporation)

The roof structure and partial slab are used to secure an enclosed space. The utilization of the existing roof structure enables a significant reduction of temporary steel materials used for constructing a temporary capping roof. Moreover, the conventional demolition method needs temporary scaffolding to cover the entire exterior of the building; on the other hand, the temporary materials can be greatly reduced with the TECOREP system, by setting up scaffolding only near the floors being demolished. This also enabled us to carry out the demolition work without putting pressure on the neighbors. (see Figure 15)

Conclusion

A new demolition system for tall buildings was developed in Japan, and the system was used to demolish the tallest building ever razed in Japan. In the Old Grand Prince Hotel Akasaka demolition – the 2nd project to use the new system – multi-story jack-down was carried out, and the demolition period was reduced. Conducting demolition work in an enclosed space brought numerous benefits from the point of ensuring the safety. In addition, reduction of environmental-pollution caused by noise and dust was confirmed.

A large number of skyscrapers have been built, and "skyscraper cities" like Manhattan, Chicago, Tokyo, and Hong Kong have emerged. But, there are decrepit buildings that have lost their property value. What to do with these structures is a critical problem we have been facing. Renovation or retrofitting is one of the solutions. Or some might prefer to scrap them and build new buildings for urban "resurgence". But we have yet to establish any demolition methods for tall buildings. In fact, few tall buildings have been demolished. Therefore it is important to consider designs on how to demolish and dismantle these structures in the near future.

Recently, it is becoming increasingly important for us to consider the environment of the earth. This system is one answer to creating new demolition methods for tall buildings. This new, clean, and ecological demolition system will push the future of tall buildings to a higher level.