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A New Demolition System for High-Rise Buildings
最新高层建筑拆除系统

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Abstract

The TECOREP system (Taisei Ecological Reproduction System) was developed as a new environmental load-reducing demolition system for ultra-high-rise buildings. The reasons for developing this new method were: Pursuit of security and safety, Consideration for the global environment and Reduction of work period and cost. In the TECOREP system, dismantling work is done in the enclosed space which is formed by the existing roof. The TECOREP system works top-to-bottom, floor-by-floor as the demolition work proceeds. The TECOREP system was used to demolish a high-rise officebuilding with a height of 105 meters in Tokyo. The following advantages were observed: contribution to the recycling-based society, providing comfort and safety to the neighbors, and reduction of overall project cost. This paper discusses the TECOREP system and the experience gained from the recent projects.

Keywords: Enclosed, Demolition, Dismantle, Jack-down, Crane, Tecorep

摘要

TECOREP系统（大成环保拆除系统）是一个适用于超高层建筑的新型环保减荷拆除系统。开发此新系统主要是为确保安全、考虑全球环境和降低施工周期和费用。在TECOREP系统中，拆除工作在一个用现有屋顶形成的封闭空间中进行。TECOREP系统从顶部到底部，逐层地进行拆除。去年TECOREP系统应用于一栋位于东京的150米高的超高层办公大楼的拆除。获得了以下的好处：帮助了循环型社会、提供了邻近社区的舒适和安全和降低了整体工程成本。本文讨论了TECOREP系统和从最近工程中获得的经验。

关键词：封闭，拆除，拆卸，千斤顶下降，吊车，Tecorep

Introduction

In recent years, the number of demolitions of high-rise buildings has been growing; in some cases, buildings over 100 meters high are being demolished. With traditional demolition methods, temporary scaffolding and sound-proof panels are set up around the outer perimeter of the building. In this method the top part of the building remains uncovered while the crawler cranes and other heavy machinery, placed next to the building, are used to tear down the building (see Figure 1).

Leaving the top of the building uncovered during the demolition work raises concerns about a potential increase in unworkable days due to weather, the scattering of dust particles in wide areas, risk of falling debris, and problems due to construction noise and vibration. Furthermore, if the building is over 100 meters high, the wind at that height will be about two times stronger than the wind at ground level, even in normal weather. This situation not only results in more hazardous setup and extra time for removal, and replacement of temporary materials, such as scaffolding and sound-proof panels, but also it is more expensive to establish safety measures. As construction is carried out over long periods, it is essential to ensure the

简介

近年来，超高层建筑拆除的数目在增加，其中包括一些高度超过100米的建筑。传统的拆除方法需要在建筑周围搭建临时的脚手架和隔音板。这个方法中，建筑的顶部是敞开的，履带吊车和重机械放置在建筑周围用来拆除（见图1）。

拆除过程中建筑顶部敞开会引起一些问题，如因为天气导致不能施工的天数增加，尘粒会散布到更大的范围，碎片降落的危险，以及施工噪声和振动等问题。而且，如果建筑高度超过100米，在该高度处的风的强度会是地面风的两倍，即使在一般天气情况下。这个情况不仅会导致更加危险的安装和更多时间来拆除，临时材料的更换如脚手架和隔音板等，而且使得建立安全措施花费更高。因为施工周期很长，确保周围人员的安全就很关键。TECOREP系统的研发就考虑到安全，环境和效率等。

TECOREP系统概述

TECOREP系统使用现有建筑的顶层，建立一个顶盖。全部拆除工作都在建筑内部进行。在移除内部装修和服务设备后，顶盖需要在结构开始拆除前建立。顶盖区域内的材料的移除需要事先计划好。TECOREP系统从顶部到底部，逐层的拆除。通过安

security and safety of the neighboring people. The TECOREP system was developed to focus on safety, consideration for environment and efficiency.

Overview Of The Tecorep System

The TECOREP system utilizes the top floor structure of the existing building, creating a "capping." The entire demolition work is completed inside the building. Following the removal of interior finishing and service equipment, the capping is built before dismantling the structure. The removal and disassembly of materials in the capped section are planned. The TECOREP system works top-to-bottom, floor-by-floor as the demolition work proceeds. The capped section moves down safely and promptly after one floor is dismantled, using the automatic descent device built into the temporary columns supporting the entire system. In addition, the TECOREP system has power generator functionality on the vertical carrier system for unloading, aimed at saving energy and the reduction of CO_2 emissions.

Structural Overview

In order to build an enclosed space for the demolition work at the top part of the building, the steel beam and the floor concrete slab at the roof level of the existing building are used as a protective roof, and new suspended protective scaffolding is set up as a surrounding wall. The columns of the building those are not necessary for the TECOREP system will be cut off and replaced with temporary columns with an up-and-down feature used to support the entire weight of the TECOREP system. The temporary columns will penetrate down to three floors below the floor being dismantled. By securing the columns with horizontal holding fixtures (guide frames) at each floor level, the columns can sustain external forces such as earthquake load and wind load. The temporary columns will be supported by temporary beams (BEAM "B") which are set up at 45 degrees angles on the existing beams two floors below the floor being dismantled. By this scheme, the weight of the TECOREP system is transferred to the structural frame of the existing building. At the time of jack-down, when the entire system is lowered, the weight of the TECOREP system will be temporarily supported by BEAM "A." Each structural element can be used on the next project with simple processing (see Figure 2).

Scheme For The Temporary Column

Each temporary column is built using two steel pillars. In order to add an up-and-down hoisting feature, a jack is built into the column. The steel pillars are designed to allow the switchover to occur between the H-shaped steel and the square pipe steel, according to the height position. During the dismantling work, the jack is stored at an H-shaped steel position to avoid becoming an obstacle. The structurally significant parts make up the square pipe steel to enhance rigidity and intensity. The temporary column is bolted onto the existing steel frame at the top and its adjacent point and the lower half of the column penetrates through the pre-set slab opening. The temporary column transfers the weight of the TECOREP system to the existing frame through BEAM "B," which is bolted together at the intermediate position of its lower section (see Figure 3).

Scheme For The Outer Suspended Protective Scaffold

The outer suspended protective scaffolding covers four sides of the building, creating an exterior wall for the enclosed space which also can be used as scaffold for dismantling the structure and inspection works. The post pipes (φ-42.6x2.4) of the scaffolding are fixed on the temporary cantilever beams at the roof of the existing building. By suspending the scaffolding from the roof structure, the scaffolding and roof structure can be jacked down together as an integrated system.

Figure 1. Traditional demolition method (source:TAISEI Corp.)
图1. 传统拆除方法（出自：大成建设）

Figure 2. TECOREP system (section) (source:TAISEI Corp.)
图2. TECOREP系统（截面）（出自：大成建设）

装在支持整个系统的临时柱子内的自动下降装置，顶盖区域在每一层拆除后会即时的安全的下移。而且TECOREP系统在用于卸载的垂直输送系统内有电机功能以节省能源和减少二氧化碳排放。

结构概述

为了在建筑顶部建立封闭空间进行拆除工作，现有建筑屋顶的钢梁和混凝土楼板用来作为保护屋顶，并搭设新的悬挂保护脚手架作为四周墙壁。TECOREP系统不需要的建筑的柱子将被拆除，代替以临时的具有升降功能的柱子以支撑TECOREP系统的重量。临时的柱子将穿透到要拆除楼层的下面三层。通过每一楼层的水平支撑构件（导向框架）来固定，临时柱子可以承担外来荷载如地震荷载和风荷载。临时的柱子用临时的梁来支撑（梁B），这个梁以45度角度搭建在拆迁层下面两层的现有梁上面。通过这个方案，TECOREP系统的重量传递到现有建筑的结构框架上。在用千斤顶下降时，当整个系统下降以后，TECOREP系统的重量将临时用梁A来支撑。每一个结构构件可以通过简单处理用到下一个工程中（见图2）。

临时柱子的设计

每一个临时柱子用两个钢柱来建造。为了增加上升和下降的升起功能，一个千斤顶放在柱子内。钢柱的设计允许根据高度在H型钢和方形钢管之间切换。在拆卸过程中，千斤顶放在H型钢内以避免成为障碍物。需要使用重要的结构部件来制造方形钢管以提高硬度和强度。临时柱子通过螺栓连接到现有的顶部和邻近的钢框架上，其底部穿过预先设好的楼板孔。临时柱子把TECOREP系统的重量通过梁B传递到现有的框架上。它们通过螺栓在下部区域的中间位置连接到一起（见图3）。

外部悬挂式保护脚手架的设计

外部悬挂式保护脚手架覆盖着建筑的四周，形成封闭空间的外墙。这个脚手架也可以用于拆除结构和检测工作。脚手架的管子

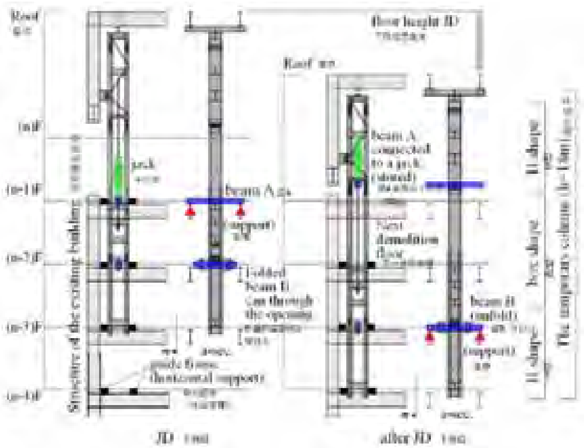

Figure 3. Scheme for the temporary column, beam A, beam B and guide frame (source:TAISEI Corp.)
图3. 临时柱子，梁A，梁B和导向框架设计（出自：大成建设）

The diagonal bracing members and wall bracing members are used to resist the wind load and are connected to the existing building. The vertical and horizontal braces are arranged in appropriate locations for enhancing rigidity and they are tied with safety wires, so that they will not fall down even in an emergency. The safety of each building component has been verified by prior strength tests.

Scheme For Beams "A" And "B"

BEAM "A" is connected to a jack located directly above, and it can move up and down through the temporary column. While the dismantling work is proceeding, it is retracted into the upper part of the temporary column along with the jack to avoid becoming an obstacle. After one floor is dismantled, BEAM "A" is lowered to the next floor which is to be dismantled for a jack-down. BEAM "A" supports the weight of the TECOREP system through a jack for a few hours during the jack-down.

BEAM "B" is bolted onto the temporary column. Immediately after jack-down starts and the weight of the TECOREP system is shifted to BEAM "A," by folding both end parts to go through the underlying slab opening, BEAM "B" descends together with the temporary column. Just before the end of a jack-down, BEAM "B" unfolds both end parts and lands to uphold the weight. By changing the joint level of BEAM "B" to the temporary column, the scheme can be adapted to the various floor heights of the existing building (see Figure 3).

Scheme For Guide Frame

The guide frame is a device to sustain a horizontal reaction force from the temporary columns at each floor level of the existing building. The guide frame also serves as a guide for the temporary columns to descend smoothly during a jack-down. The guide frames are relocated sequentially as the demolition work proceeds to the lower levels.

Application To Tokyo Office Building

Overview Of The Building

The office building targeted for the demolition system was a 105-meter high steel structure with 24-stories, and a 1-story rooftop shack. The building had an area of 1,750 square meters with approximately 70 meters on the long side and approximately 25 meters on the short side. The exterior wall was built with natural stone-clad curtain walls (see Figure 4).

Execution Plan

The protective scaffolding at the perimeter was built up with 12 stages and set up from the top to two floors below the floor which

（ф-42.6x2.4）固定在现有建筑屋顶的临时悬臂梁。通过从屋顶悬挂脚手架，脚手架可以和屋顶结构作为一个整体用千斤顶下降。对角支撑构件和墙支撑构件用来抵抗风压并连接到现有建筑上。垂直和水平托架安置在合适的位置以提升刚度，用安全网连在一起以确保在紧急情况下不会掉下来。每座建筑构件的安全性已事先通过强度试验来验证过。

A梁和B梁的设计

A梁与位于上部的千斤顶连接，可以通过临时柱子上下移动。当进行拆除工作是，它可以和千斤顶一起收缩到临时柱子的顶部以避免成为障碍。当一个楼层拆除后，A梁通过千斤顶下降到以一个拆除楼层。在下降过程中A梁通过千斤顶支撑TECOREP系统的重量几个小时。

梁螺栓连接到临时柱子上。当千斤顶下降时，TECOREP系统的重量立即传递到A梁上，通过折叠末端部件来通过楼板上的孔，梁B也与临时柱子一起下降。当下降即将结束时，梁B会打开两个末端部件来支撑重量。通过改变梁B和临时柱子的连接程度，这个设计可以适应现有建筑的不同楼层高度（见图3）。

导向框架的设计

导向框架是用来承受来自临时柱子在现有建筑每一楼层的水平应力的装置。导向框架在下降过程中也用来做为临时柱子下降的导向。当拆除工作进行到下一楼层时，导向框架也相应转移。

东京办公大楼的应用实践

大楼概述

要拆除的办公大楼是105米高，24层的钢结构结构和1层的屋顶小屋。该建筑有1750平方米的建筑面积，长边有大约70米，短边有大约25米。外墙是天然石头组成的幕墙（见图4）。

Figure 4. An office building in Tokyo (source:TAISEI Corp.)
图4. 位于东京的一栋办公大楼（来源：大成建设）

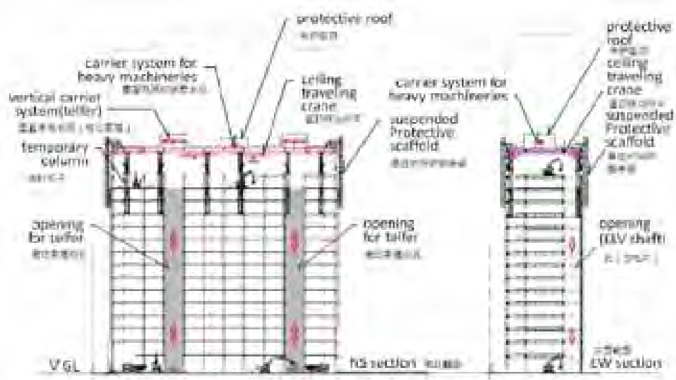

Figure 5. General temporary work scheme (source:TAISEI Corp.)
图5. 临时施工的总设计（出自：大成建设）

was being demolished. The scaffolding was sustained horizontally by connecting it to the exterior wall using a vertically sliding connecter. The 12 temporary steel columns were set up at the perimeter of the capped section to uphold the TECOREP system. The temporary columns were used to sustain the entire capped section, but they were also capable of descending by one floor height automatically after a typical floor was dismantled. A step-rod-type hydraulic jack was used for the descending system. The horizontal and vertical conveyance was performed by the ceiling traveling crane and telfer that were set up on the roof structure. There were two openings inside the building for unloading dismantled materials (see Figure 5).

Steps For Setting Up The Tecorep System

In order to construct the TECOREP system, it was first determined what area on the roof would be needed and prescribed advanced demolition work was performed (see Figure 6 step 1). Then, the temporary crane for the assemblies was set up on the steel structure of the roof, with each unit of the outer protective scaffolding lifted by the crane and connected to the steel structure of the roof, and temporary columns were set up by the crane to hold up the entire weight of the TECOREP system. Each added component, such as the scaffolding or temporary columns, were connected to the existing frame by bolts (see Figure 6 step 2). With this, the installation of temporary materials required for TECOREP was complete. Next, the top floor was demolished in advance to make space for demolition work used by the TECOREP system. By shifting the weight of the TECOREP system from the existing columns to the temporary columns, the setup of the TECOREP system was complete (See Figure 6 step3). Subsequently, the floor covered by the TECOREP system was dismantled, and jack down performed (see Figure 6 step 4, 5).The same steps were repeated for dismantling (see Figure 6 step 6).

Verification Of Safety

The safety of the TECOREP system in combination with the existing building was analyzed, using the same criteria for evaluating Japanese skyscraper projects in case of small-to-midsized earthquakes (level 5 on the Japanese scale). The elastic range was evaluated in case of large-scale earthquakes (level 7 on the Japanese scale) and it was confirmed that the system would not fall over the duration of demolition work.

The measure against a typhoon (wind speed over 34 m/s) was anticipated by adding a temporary bracing element steel pipe, according to the size of the typhoon.

Advantages Of The System

Advantage In Locations Where There Are Many Restrictions

There was limited open space within the Tokyo building's site. The site was also surrounded by buildings as tall or taller, and the building was built to the utmost limit of the site boundary. In addition, there was only so much space available for unloading dismantled materials using the cranes, as new building construction work was proceeding concurrently with the demolition work. With the TECOREP system, the demolition work, as well as unloading of dismantled materials, was done in a capped section formed at the top of the building. The system effectively allowed work to proceed without any delay in construction schedule, despite the many location restrictions (see Figure 7).

Advantages Of Conducting Demolition Work Within The Enclosed Space

Various advantages in using the TECOREP system were confirmed in the project, as the entire demolition work was done by enclosing the top and sides of the floor being demolished. From the start of

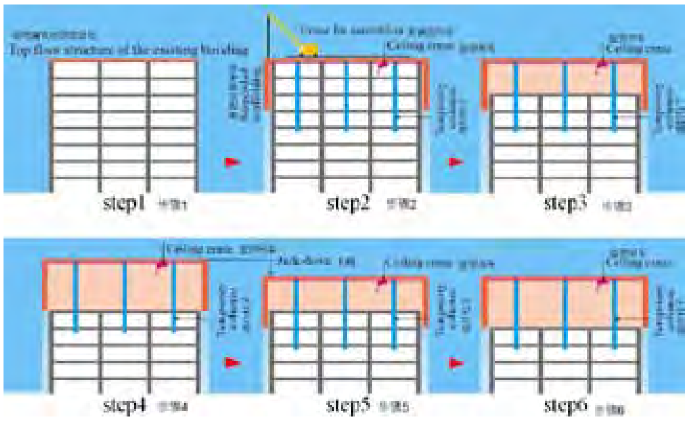

Figure 6. Steps for setting up the TECOREP system (source:TAISEI Corp.)
图6. 搭建TECOREP系统的步骤（出自：大成建设）

实施计划

周围的保护脚手架建造为12段，安装在从顶部到拆除楼层下面两层。脚手架通过垂直的连接器水平的连接到外墙上。12个临时的钢柱建在顶盖区域的周围以支撑TECOREP系统。临时钢柱用来支撑整个屋顶区域。当一个典型楼层拆除后，它以可以自动下降一个楼层高度。步棒型水力千斤顶用来作为下降系统。水平和垂直输送是通过屋顶的吊车和安装在屋顶结构上的电动索道。建筑内有两个开口可以卸下拆除的材料（见图5）。

设立TECOREP系统的步骤

为了建造TECOREP系统，需要在拆除工作开始前先确定屋顶的哪些区域需要保留（见图6步骤1）。接着，将安装用的临时吊车安装在屋顶的钢结构上。外部保护脚手架的部件通过吊车吊上来并连接到屋顶钢结构上。临时柱子用吊车安装用来支撑整个TECOREP系统。每一个附加部件，如脚手架和临时柱子，都通过螺栓连接到现有框架上（见图6步骤2）。在这一步，TECOREP系统需要的临时材料的安装就完成了。下一步，先拆除顶层以留出空间便于TECOREP系统工作。将TECOREP系统的重量从现有柱子转到临时柱子上，TECOREP系统的安装就完成了（见图6步骤3）。然后，TECOREP系统覆盖的楼层被拆除，通过千斤顶降下整个系统（见图6步骤4和5）。拆除工程中重复这些步骤（见图6步骤6）

安全验证

应用评价日本摩天大厦工程的标准在小到中等规模的地震（日本震级5级）情况下对TECOREP系统与现有建筑的综合起来的安全性进行了分析。使用大规模地震（日本震级7级）对弹性程度进行了评价并确认了整个系统在拆除过程中不会倒。

根据台风大小,通过增加一个临时支撑钢管来抵抗预计的台风（风速34米/秒）。

系统优点

在有场地限制的场合体现出的优点

东京这栋建筑的场地空间有限。周围有高的和更高的建筑，并且这栋建筑建在场地的最边界上。因为有新的建筑工程在与拆除工作同时进行，场地只有通过吊车进行卸载的空间。采用TECOREP系统，拆除工作和拆除材料的卸载都在建筑顶部形成的顶盖区域内进行。尽管有场地限制，本系统成功的让工作没有耽搁的安装施工计划进行（见图7）。

在密封空间内进行拆除工作的优点

在这个工程中TECOREP系统的不同的优点得到确认，因为整个拆除工作是在屋顶和要拆除的楼层的周围形成的密封空间内进行。从开始拆除典型楼层开始，工程没有因为天气原因而耽误过，典型楼层拆除的可工作时间几乎是100%。考虑到对抗坏天气而需要

Figure 7. Work proceeding situation (source:TAISEI Corp.)
图7. 施工过程进展情况（来源：大成建设）

the demolition work of typical floors, the project experienced no unworkable days due to bad weather .and the work operability of the typical floor demolition was almost 100%. The project managers provisioned for more than a 10% delay in construction work, considering the labor for preparation and removal of measures against bad weather; however, the work proceeded without any delay. By sealing off the work area, the new system significantly reduced the noise level and dust scattering, which were the major concerns of traditional demolition methods. According to the sound pressure level comparison measurement, the construction noise was reduced by 20dB. Both outside air quality and indoor air quality in the working space were kept normal by 10 times of air change count with a removal filter of pushpull ventilation facilities. These performances were not possible with the traditional method, and the new method demonstrated substantial cost effectiveness (see Figure 8).

Reduction Of Temporary Materials

The roof structure and partial slab were used to create a capped section. The utilization of the existing roof structure led to a significant reduction of temporary steel materials otherwise needed to form the roof of the capping. Moreover, with the traditional demolition method, temporary scaffolding was built to cover the entire exterior of the building. With the TECOREP system, on the other hand, by setting up scaffolding only near the floors being demolished, the volume of temporary materials was greatly reduced. This also enabled the project managers to carry out the demolition work without creating conflicts with neighbors (see Figure 9).

的准备工作，项目经理预计了超过10%的施工耽搁。然而，施工工作没有任何耽搁。通过封闭整个施工区域，本新系统显著的降低了噪声和灰尘散布，而这些通常是传统的拆除工作主要关心的问题。通过声压对比测量，施工噪声降低了20dB。通过对吸吹式通风系统的过滤器的10倍的空气更换频率，施工场所内外的空气质量都在正常水平。这个表现是传统方法达不到的。而且新方法证明了有效的成本效益（见图8）。

临时材料的减少

屋顶结构和一些楼板用来做为顶盖区域。使用现有的屋顶结构显著的减少了形成顶盖所需要的临时钢材料。传统的拆除方法需要临时脚手架覆盖在整个建筑外部。而TECOREP系统只需要在要拆除的楼层周围设立脚手架，临时材料的需要很大程度的减少了。这也使得项目经理可以与周围邻居没有冲突的进行拆除工作（见图9）。

安全保证和人工减少

每一楼层拆除后通过千斤顶下降，TECOREP系统自动为下一楼层拆除降下顶盖区域。对于办公大楼TECOREP系统的通过千斤顶的下降每3.925米（楼层高度）重复一次，下降一个楼层需要的时间大约是2个小时。本工程证明了每次下降可以在大约3个小时内完成，包括初始的安装。很难在类似的情况下进行比较，但是如果悬挂式临时脚手架需要拆除，通常需要大约一天的时间。考虑到安全措施的安装，施工周期可以缩短一个月（从12个月到11个月），并且有明显的费用降低（见图10）。

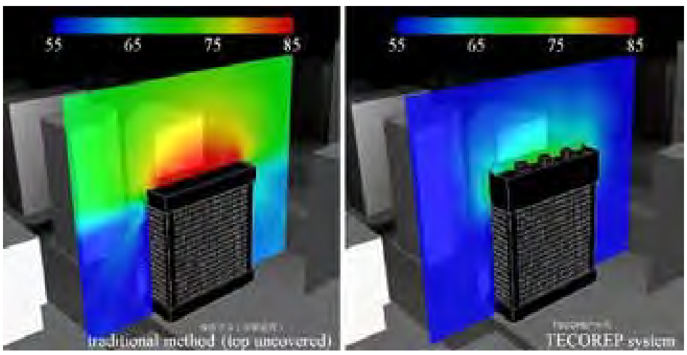

Figure 8. Reduced the noise level (source: TAISEI Corp.)
图8. 噪声的降低（出自：大成建设）


Figure 9. The utilization of the existing roof structure (source:TAISEI Corp.)
图9. 使用现有建筑屋顶结构（出自：大成建设）

Figure 10. Safety and automatically jack-down system (source:TAISEI Corp.)
图10. 安全和自动下降系统（出自：大成建设）

Safety Assurance And Reduction Of Labor

By jacking-down after each floor was dismantled, the TECOREP system automatically lowered the capped section for dismantling work to the lower floor. The jack-down of the TECOREP system was repeated every 3.925 meters (floor height) for the office building, and the time it took to descend one floor was about two hours. The project demonstrated that the jack-down can be completed in approximately three hours, including the preliminary setup. It is difficult to make comparisons on a like-for-like basis; however, if any suspended temporary scaffolding was moved by dismantling in units, it was assumed to take approximately one day. Taking the setup of safety measures into consideration, the period of construction was reduced about one month (12 months to 11 months), with the subsequent cost reduction(see Figure 10).

Reduction In Power Usage During Construction

The vertical transport system (telfer) was built with a regenerative brake system. In this project, the electricity saved on each up and down trip was measured by using various weight conditions. The heavier a weight, the production of electricity increases. It was found that approximately 2,000KJ of electricity was generated by this system at the general weight (4 tons), and that approximately 5,100KJ of electricity was generated at the maximum weight (8 tons). On the other hand, 4,800KJ of electricity was consumed without this system (see Figure 11).

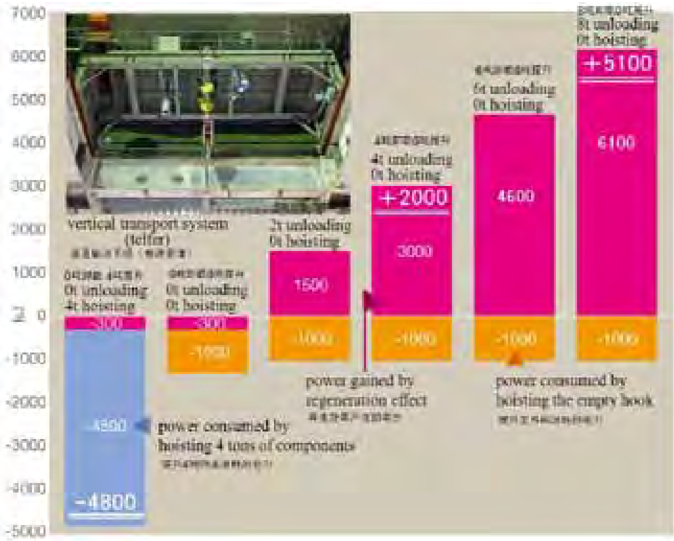

Figure 11. The power generation at various loads (source:TAISEI Corp.)
图11. 不同荷载下的电力产生（出自：大成建设）

施工期间电力的减少

垂直输送系统（电动索道）配有再生制动系统。本项目每次升降所节省的电力通过不同的重量情况来测量。重量越重，产生的电力也增加。在总重量4吨情况下，本系统产生的电力大约在2000 KJ，最大重量8吨的情况下产生的电力大约在5100 KJ。另一方面，没有本系统的情况下消耗的电力约为4800 KJ （见图11）。

Conclusion

A new demolition system for high-rise buildings was developed and used for the first time in the demolition of an office building in Tokyo. From the point of view of security and safety, demolition work in an enclosed space brought numerous benefits. With the traditional demolition method, the building is gradually destroyed as demolition work proceeds; however, with the TECOREP system, the height of the building lowered slowly with the progress of the demolition work, and it does not, in any way, look like demolition work is going on inside the building. Moreover, closing off the work area not only shortens the work period by reducing the number of unworkable days due to weather, but also significantly reduces the generation of noise and the scattering of dust particles. The safely shifting down of capped sections can work effectively in demolitions of buildings taller than 200 meters, using the automatic descending mechanism. Technological development aimed at application to various structure types and further enhancing efficiency will be promoted.

结论

用于超高层建筑的一种新型的拆除系统研发出来并首次应用于东京的一栋办公大楼的拆除。在安全角度，拆除工作在封闭环境中进行带来了很多优点。在传统的拆除方法中，随着拆除工作的进行建筑逐渐被破坏。在TECOREP系统中，随着拆除工作的进行建筑高度逐渐降低，看不出来拆除工作正在建筑内部进行。更进一步的是，施工场所的封闭不仅能够缩短因为天气原因不能工作的天数，而且显著的降低了噪声的产生和灰尘的散布。采用自动下降系统，顶盖区域安全的下降可以有效的应用于高度在200米以上的建筑的拆除。所研发出来的技术的目标是可以应用于各种不同的结构。下一步是进一步提高效率。