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THE PRESENT STATE AND ISSUES ON RETROFITTING OF HISTORIC TIMBER-FRAMED BRICK CONSTRUCTION BUILDINGS IN JAPAN

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ABSTRACT: In the late 19th century, the method of timber-framed brick construction (TFBC, "mokkotsu-rengazo" in Japanese) was introduced to Japan as a western technique. After a while, it became apparent that the TFBC method was vulnerable to earthquakes, and hence, it was not used anymore. However, some TFBC buildings remain in Japan, and several of them require reinforcement. To ensure appropriate and smooth repairs, this paper summarizes the history, past retrofitting works, and current situation and issues regarding the restorations of TFBC buildings in Japan through document survey and building investigations.
We reveal that only a few buildings have been retrofitted seismically, and several buildings still require appropriate restoration. In the current Japanese administration of cultural properties, retrofitting entails highly detailed seismic assessment and reinforcement methods, which results in a limited number of restorations. In addition, lost techniques, including the TFBC method, has not been treated as a significant subject of research. Hence, relevant literature is limited, and detailed knowledge on the topic is lacking. As predicting the occurrence of large earthquakes is not possible, development of reinforcement methods, expansion of systems to support repairs, and study on technical-historical evaluations are necessary.

KEYWORDS: Timber Framing, Brick, Reinforcement, Earthquake, Architectural Conservation, Cultural Property

1. INTRODUCTION

In the late 19th century, the Japanese government hired foreign experts to import the latest technology and systems that modernized and westernized the country. Bricks were the first architectural materials to be implemented as a part of this policy. They were considered cutting-edge materials that had fire resistance and could represent advances. In addition to piling them up, another method for brick construction was timber-framed brick construction (TFBC, "mokkotsu-rengazo [木骨煉瓦造]" in Japanese). The TFBC is a construction method that combines timber frames and brick masonry walls to form walls, primarily exterior walls. However, the use of this method was discontinued after several TFBC buildings were damaged by the earthquakes. However, some TFBC buildings still exist, many of which require restoration.
In this study, we examined the current situation and issues regarding the restoration of TFBC buildings in Japan. The remainder of the paper is organized as follows. Section 2 introduces existing TFBC buildings and their history. Section 3 describes past restoration works. In Section 4, we discuss issues regarding current restoration from the perspective of the system of cultural property protection and historical evaluation in Japan. Section 5 provides the conclusion and future research directions.
The TFBC buildings covered in this study are all national cultural properties.

2. TIMBER-FRAMED BRICK CONSTRUCTION IN JAPAN

2.1 EXISTING BUILDINGS

According to the database of the Agency for Cultural Affairs and the author's research [1], there are 23 TFBC buildings among the national cultural properties in Japan (Figure1, Table 1).

2.2 BRIEF HISTORY [1,2]

2.2.1 The 1860s – the 1880s: Import of TFBC

From the end of the Edo era to the Meiji era, French engineers, such as Edmond Auguste Bastien began the construction of Yokosuka Naval Shipyard in 1865 and Tomioka Silk Mill in 1871. With the start of trade with foreign countries, housing for foreigners, such as the Jugobankan Building in the Former Kobe Foreign Concession (1881) was also built. Similarly, Marc Marie de Rotz, who was a Christian missionary, designed their religious facilities, such as the Former Latin Seminario (1875). Thus, timber-framed masonry was used in relatively large public buildings during this period. The main constructional feature in this period was brick walls filled inside the frame (wall type A, Figure 2).

2.2.2 The 1890s – 1910s: Modification of TFBC

In 1891, the Mino-Owari Earthquake (Nobi Earthquake) caused severe damage to brick buildings. Subsequently, TFBC was used less frequently in public buildings.

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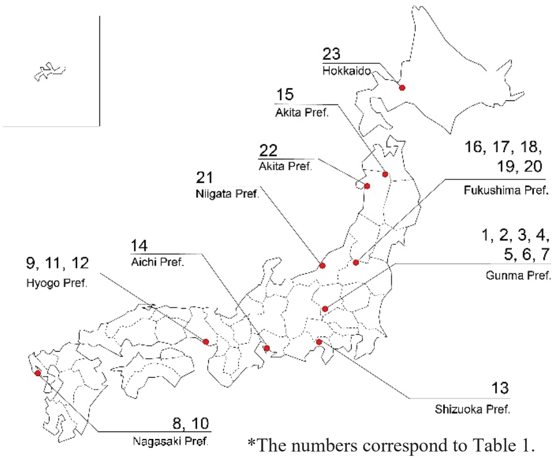

*The numbers correspond to Table 1.

***Figure 1**: Location of existing TFBC buildings in Japan*

However, as the domestic production of bricks increased, TFBC was used more in private residences and corporate buildings, such as the Former Kabuto Beer Factory (1898). Some TFBC warehouses built in houses are fused with traditional Japanese construction methods. The main constructional feature in this period was brick walls covering the exterior of the timber frame (wall types B or C, Figure 2).

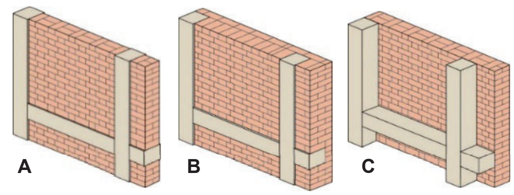

***Figure 2**: Wall type of existing TFBC buildings in Japan [1]*

***Table 1**: List of existing TFBC buildings in Japan [1]*

No.	Building Name	Grade*	Location (Prefecture)	Construction Year	Wall Type	Seismic Retrofit	Retrofitting Method
1	The West Cocoon Warehouse, Tomioka Silk Mill	NT	Gunma	1872	A	Done	Steel Frames, Glass Ceilings, AFRP Rods
2	The East Cocoon Warehouse, Tomioka Silk Mill	NT	Gunma	1872	A	Partially Done	Steel Frames, Wire Meshes, Gap Filling
3	The Silk-Reeling Plant, Tomioka Silk Mill	NT	Gunma	1872	A	Not Yet	
4	The Cocoon Drying Facility, Tomioka Silk Mill	NT	Gunma	1872	A	Not Yet	
5	The Director's House (Brunat House), Tomioka Silk Mill	NT	Gunma	1873	A	Not Yet	
6	The Dormitory for French Female Instructors, Tomioka Silk Mill	NT	Gunma	1873	A	Not Yet	
7	The Inspector's House, Tomioka Silk Mill	NT	Gunma	1873	A	Not Yet	
8	The Former Latin Seminario	ICP	Nagasaki	1875	A	Not Yet	
9	The Jugobankan Building in the Former Kobe Foreign Concession	ICP	Hyogo	1881	A	Done	Seismic Isolation, SRC Columns, Steel Frames
10	The Seine Factory, Former Shitsu Aid Center	ICP	Nagasaki	1883	A	Not Yet	
11	The Former Hunter House	ICP	Hyogo	1889**	A	Not Yet	
12	The Annex Building of Ijokaku	RTCP	Hyogo	1890**	B	Not Yet	
13	The Brick Warehouse, Yoshizawa House	RTCP	Shizuoka	1891	B	Not Yet	
14	The Former Kabuto Beer Factory	RTCP	Aichi	1898	A	Done	Steel Frames, Steel Buttresses
15	The Former Engine Room of Kosaka Mine Manufacturing Division	ICP	Akita	1904	A	Done	Reinforcing Columns and Beams, RC Foundation
16	The Brick Warehouse, Wakaki Shop	RTCP	Fukushima	1904	B	Not Yet	
17	The Agricultural Work Warehouse, Wakana House	RTCP	Fukushima	1910	B	Not Yet	
18	The Brick Warehouse, Ueno House	RTCP	Fukushima	1911	B	Not Yet	
19	The Kurazashiki, Wakana House	RTCP	Fukushima	1916	B	Not Yet	
20	The Third-floor Warehouse, Wakana House	RTCP	Fukushima	1916	B	Not Yet	
21	The New Warehouse, Takahashi Sake Brewry	RTCP	Fukushima	1922	C	Not Yet	
22	The Rice Warehouse, Kodama House	ICP	Akita	1923	C	Not Yet	
23	The Suginome House	RTCP	Hokkaido	1933	C	Not Yet	

* "NT" = National Treasure, "ICP" = Important Cultural Property, "RTCP" = Registered Tangible Cultural Properties
** Exact year of construction is unknown, so an estimated year is given.

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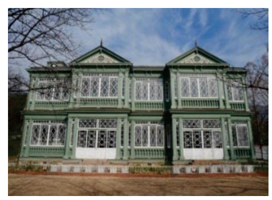
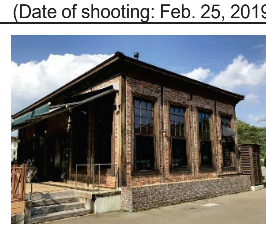
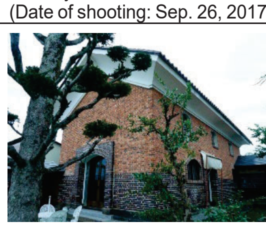
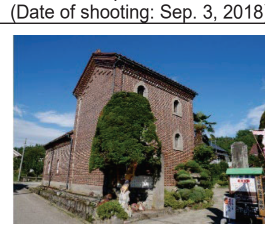
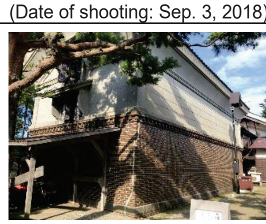
Table 2: *Exterior view of existing TFBC buildings in Japan*

 1. The West Cocoon Warehouse, TSM* (Date of shooting: July 4, 2022)	 2. The East Cocoon Warehouse, TSM* (Date of shooting: July 4, 2022)	 3. The Silk-Reeling Plant, TSM* (Date of shooting: Oct. 21, 2017)	 4. The Cocoon Drying Facility, TSM* (Date of shooting: Oct. 21, 2017)
 5. The Director's House (Brunat House), TSM* (Date of shooting: Oct. 21, 2017)	 6. The Dormitory for French Female Instructors, TSM * (Date of shooting: July 4, 2022)	 7. The Inspector's House, TSM* (Date of shooting: July 4, 2022)	 8. The Former Latin Seminario (Date of shooting: July 10, 2022)
 9. The Jugobankan Building in the Former Kobe Foreign Concession (Date of shooting: Feb. 25, 2019)	 10. The Seine Factory, Former Shitsu Aid Center (Date of shooting: July 8, 2022)	 11. The Former Hunter House (Date of shooting: Feb. 25, 2019)	 12. The Annex Building of Ijokaku (Date of shooting: Feb. 25, 2019)
 13. The Brick Warehouse, Yoshizawa House (Date of shooting: July 21, 2017)	 14. The Former Kabuto Beer Factory (Date of shooting: Sep. 26, 2017)	 15. The Former Engine Room of Kosaka Mine Manufacturing Division (Date of shooting: Sep. 10, 2019)	 16. The Brick Warehouse, Wakaki Shop (Date of shooting: Sep. 3, 2018)
 17. The Agricultural Work Warehouse, Wakana House (Date of shooting: Sep. 3, 2018)	 18. The Brick Warehouse, Ueno House (Date of shooting: Sep. 3, 2018)	 19. The Kurazashiki, Wakana House (Date of shooting: Sep. 3, 2018)	 20. The Third-floor Warehouse, Wakana House (Date of shooting: Sep. 3, 2018)
 21. The New Warehouse, Takahashi Sake Brewry (Date of shooting: Sep. 13, 2019)	 22. The Rice Warehouse, Kodama House (Date of shooting: Sep. 9, 2019)	 23. The Suginome House (Date of shooting: Sep. 24, 2019)	

* "TSM" = Tomioka Silk Mill

2.2.3 The 1920s and beyond: Decline of TFBC

In 1923, the Tokyo-Yokohama earthquake (Kanto Earthquake) devastated masonry buildings (Figure 3). The following year, the Urban Building Law (Shigaichi kenchikubutsu hou [市街地建築物法]) (1919) became stricter, which made it difficult to construct masonry buildings in Japan. The use of TFBC was rapidly decreased. This strict standard was implemented into the current the Building Standard Law (Kenchiku kijun hou [建築基準法]) enacted in 1950.

Figure 3: *Damage to TFBC building during Tokyo-Yokohama Earthquake (1923) [3]*

2.3 VULNERABILITY TO EARTHQUAKES

Timber frames and brick walls are not structurally joined together; therefore, their vibration characteristics are different during earthquakes. Consequently, there is a high risk of failure in the out-of-plane direction. In 1995, the Kobe earthquake destroyed the Jugobankan Building in the Former Kobe Foreign Concession (Figure 4).

Figure 4: *The Jugobankan Building before (left) and after (right) the Kobe Earthquake (1995) [4]*

3. PAST RESTORATION WORKS

3.1 THE JUGOBANKAN BUILDING IN THE FORMER KOBE FOREIGN CONCESSION

This building is located in Kobe City in the southern part of Hyogo Prefecture, and is designated as an important national cultural property. After its collapse in the Kobe earthquake in 1995, it was reconstructed and reinforced from 1995 to 1998. Two goals were set for seismic retrofitting. First, seismic isolators were installed in the foundation to decrease the seismic forces. Second, to increase the horizontal load-carrying capacity, two steel reinforced concrete (SRC) columns (Figure 6) were set up in place of the original chimneys and connected to steel frames added inside the roof truss and second-floor framing [4].

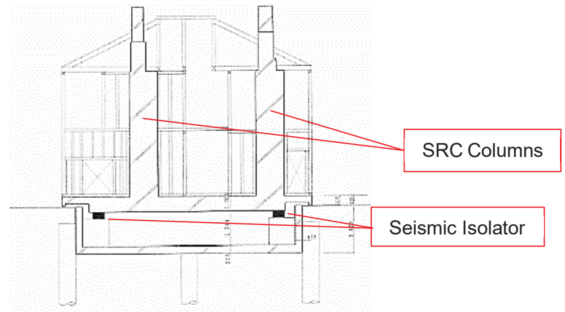


Figure 5: *Cross-section of Reinforcements (SRC columns and seismic isolators) of the Jugobankan Building [4]*

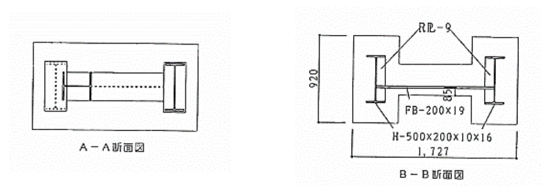


Figure 6: *Cross-sectional view of SRC columns [4]*

3.2 THE FORMER KABUTO BEER FACTORY

This building is located in Handa City in the southern part of Aichi Prefecture. It is registered as a national tangible cultural property and was restored in 2014. Steel braces and buttresses were installed to increase the horizontal load-carrying capacity, and pillar legs and beams were reinforced with metal fittings.

Figure 7: *Reinforcements of the Former Kabuto Beer Factory (left: steel frame and brace, right: steel buttresses)*

3.3 THE WEST COCOON WAREHOUSE OF FORMER TOMIOKA SILK MILL

This building is located in Tomioka City in the southern part of Gunma Prefecture and is designated as a national treasure and UNESCO World Heritage Site. It was restored between 2014 and 2020. Two main goals were set for seismic retrofitting. First, to increase the horizontal load-carrying capacity, a variety of reinforcements were installed, such as steel frames, braces, and glass ceilings,

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which had less influence on the original interior design. Second, to increase the in-plane strength of brick walls, aramid fibre-reinforced plastic (AFRP) rods were embedded in masonry joints [5].

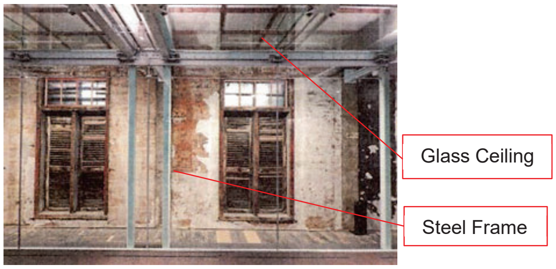

Figure 8: Reinforcements at the West Cocoon Warehouse: interior view [5]

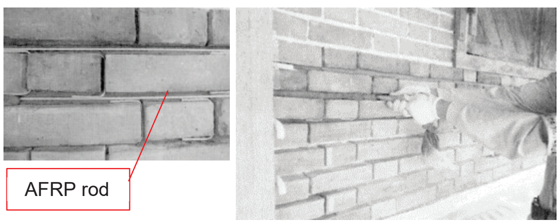

Figure 9: Inserting of AFRP rods into brick wall of the West Cocoon Warehouse [5]

3.4 THE EAST COCOON WAREHOUSE OF FORMER TOMIOKA SILK MILL

This building is a counterpart to the West Cocoon Warehouse, and is also a national treasure and a UNESCO World Heritage Site. Although not yet fully reinforced, transitional reinforcement work was conducted between 2011 and 2012 to reduce the out-of-plane damage from earthquakes. The work includes the following: filling the gaps between the top of the brick wall and wooden girder with mortar, setting up wire meshes, and reinforcing columns and beams on the brick walls facing a busy passageway [6].

Figure 10: Reinforcements at the East Cocoon Warehouse (left: zoom out view, right: zoom in view), (Date of shooting: July 4, 2022)

3.5 FORMER ENGINE ROOM OF KOSAKA MINE MANUFACTURING DIVISION

This building is located in Kosaka Town in the northern part of Akita Prefecture and is registered as a national tangible cultural property. Originally part of a mining facility, it was relocated and restored in 2015, and is now a coffee shop. During relocation, a new reinforced concrete foundation was cast, and reinforcing columns and beams made of laminated wood were added to the interior of the building.

Figure 11: Reinforcements at the Former Engine Room of Kosaka Mine Manufacturing Division: interior view (Date of shooting: Sep. 10, 2019)

4. RETROFITTING ROADBLOCKS

4.1 “AUTHENTICITY” PERSPECTIVE

The concept of “authenticity” in architectural conservation comprises the following sources: design, materials, craftsmanship, setting, use and function, and spirit and feeling. The Nara Document on Authenticity (1994) states that “the respect due to all cultures requires that heritage properties must be considered and judged within the cultural contexts to which they belong [7].” However, the frequent disasters and humid temperate climate make it to be difficult to perfectly preserve the materials and elements which made using the techniques of the time. Therefore, these factors are not equal, and design is often considered the most important factor. For examples, the original joint material was lost when embedding AFRP rods into the joints of brick walls of the West Cocoon Warehouse (Figure 9), and the original foundations were excavated when installing a seismic isolator under the Jugobankan Building (Figure 5).

4.2 JAPANESE ADMINISTRATION OF CULTURAL PROPERTIES

4.2.1 Framework of Cultural Property Building and Subsidy System

In the Japanese Administration of Cultural Properties, national cultural property buildings are classified into two categories. First is important cultural properties (ICP) and national treasures (NT), and the other is registered tangible cultural properties (RTCP). The former is a designation system with strict regulations on their restorations, and ICP of especially high value are designated as NT to safeguard the material, structural system, and building techniques. In these conservation projects, after an assessment by the government, the national treasury pays 50% of the repair costs: repair work costs, disaster prevention work costs, other construction costs, information dissemination costs, design, and construction supervision costs (additional amounts might be added depending on the subsidized organization, project size, region, etc.). In addition, when using government subsidies, the person in charge of the design and construction supervision must be a conservation architect certified by the Agency for Cultural Affairs.

Conversely, the latter is a registration system based on requests from owners and local governments and allows for relatively flexible preservation and utilization, including renovation and conversion. In these conservation projects, after an assessment by the government, the national treasury mainly pays 50% of the design and construction supervision costs. As with ICP and NT, the amount of subsidy can be more in some cases, and the person in charge of design and construction supervision must be a conservation architect certified by the Agency for Cultural Affairs [8-10].

Most TFBC buildings, including non-cultural properties, currently remain unrestored because seismic retrofitting of such vulnerable structures requires a large amount of funding, and the evaluation system for the historical value of TFBC method has not adequately been established.

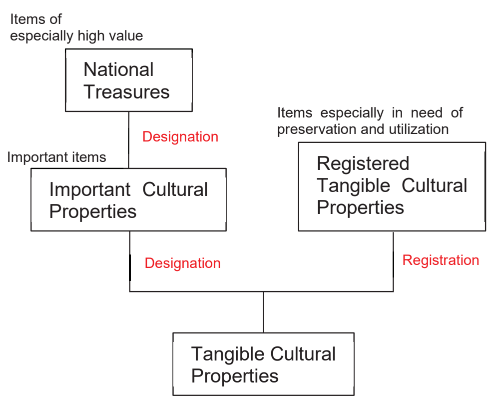

Figure 12: *Schematic diagram of Japanese cultural properties (structures) [8]*

4.2.2 Steps to Seismic Retrofitting

The repair and management of cultural property buildings is the responsibility of the owner. However, because seismic retrofitting requires a high degree of expertise, technical assistance is provided from the local and national governments during the entire process.

In the case of wooden ICP and NT, under the Law of Protection of Cultural Properties (Bunkazai hogo hou [文化財保護法] in Japanese), before repair work, seismic assessment must be conducted, which is divided into three stages (Figure 13): preliminary seismic assessment (PSA), basic seismic assessment (BSA), and expert seismic assessment (ESA). PSA is sufficiently simple; the owners can perform it by themselves, and it is used to determine the urgency of repair or a more detailed assessment. Both BSA and ESA are used to quantitatively evaluate seismic resistance through structural surveys and structural analysis; however, the difference is that the former is non-destructive, while the latter is more detailed because it includes destructive surveys with dismantling and repair, as required. In the case of non-wooden ICP and NT, PSA might not be conducted and the process may start with BSA or ESA, depending on the characteristics of the building. If this assessment process reveals that the current seismic capacity does not meet the criteria, seismic retrofitting is planned as soon as the budget is available. Conversely, RTCP buildings are restored in accordance with the Building Standard Law, which is the standard for new buildings (however, an exemption from the Building Standard Law might be permitted through a third-party committee assessment) [6].

Thus, there is a strict assessment process to complete the seismic retrofitting of cultural properties; this process might require to a year or occasionally even more. Seismic retrofitting without a correct understanding of the structural characteristics of the building may result in significant earthquake damage and hence must be performed carefully. In particular, seismic assessment of TFBC buildings tends to take long because of large-scale structural experiments and material experiments [5], and the restoration experience is still limited. Therefore, it is necessary to not only conduct a structural survey of individual buildings but also elucidate the general structural characteristics of TFBC.

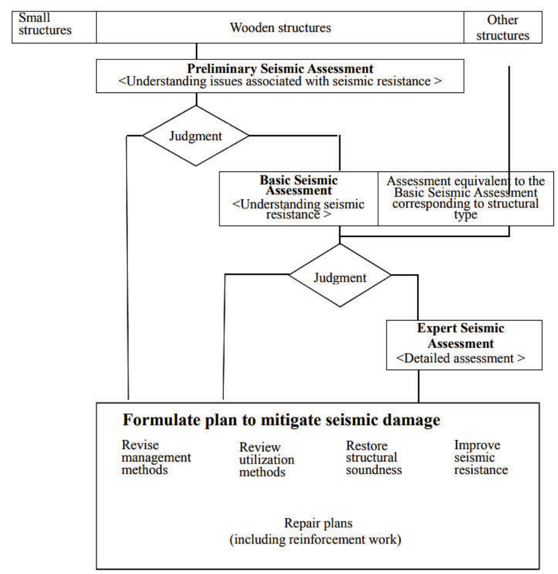

Figure 13: *Flow chart of seismic assessment and formulation plan [11]*

4.3 TECHNICAL-HISTORICAL EVALUATION OF TFBC

As discussed in Section 2, the TFBC method was introduced and subsequently abandoned. However, the details of TFBC, namely, what type of technology TFBC is, how it is merged with the local methods, and how it is transformed, have not yet been adequately discussed. For example, the database of the Agency of Cultural Affairs lists buildings that are categorized as TFBC but are purely brick masonry or use two construction methods separately in single buildings. Similarly, it contains TFBC buildings, which are categorized as brick masonry buildings. This suggests that the TFBC method is not clearly defined, and that there is no common view of the method among experts, municipalities, and building owners. Specifically, the accumulation of knowledge about the lost technique is insufficient.

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In Japan, the few studies on TFBC to date have not obtained its complete view, either because they are case studies [12, 13] or take some of the features of TFBC and place them in technical history [3, 14]. Therefore, in the future, it is necessary to typify the original form and the form that has subsequently changed in Japan, to compare them with the TFBC structures in France and other European countries, to reveal the mechanism of the transition and the decline of foreign construction methods in Japan, and to establish and apply more appropriate survey and historical evaluation methods for existing buildings.

5. CONCLUSIONS

In Japan, the TFBC structure is a Western-derived construction method that was in use for approximately 70 years. There are 23 existing buildings, but only five of them have been reinforced to withstand earthquakes. To repair earthquake-vulnerable cultural property buildings, including TFBC buildings, a precise seismic assessment is required. Currently, because of the significant time and cost involved, adequate earthquake countermeasures have not yet been taken.

Since it is impossible to predict when a large earthquake will occur, it is necessary to develop reinforcement methods, including transitional reinforcement, as shown in the East Cocoon Warehouse of the Tomioka Silk Mill; expand systems to support repairs; study technical-historical evaluations to ensure appropriate and smooth repair work.

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