A Study of Stone-joint Metal Clamps in China and Korea during the 6th-8th Centuries*

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The use of stone-joint metal clamps to bind cut-stone blocks is a structural reinforcement device in masonry construction. Popularly called "keystone cut clamps" in the Western world, their emergence seems to have coincided with the advent of dry ashlar masonry, which required new approaches in structural engineering.[1] They signify a technical evolution in the manipulation of stones in human history and bespeak the inseparable unity of art and technology down to the last detail.

Stone-joint clamps have been found globally stretching from South America all the way to the Far East, covering a long span of time **[Fig. 1]**.[2] By present knowledge, the earliest datable examples come from Egyptian temples of the middle of the second millennium BCE in the shape of a flat rectangular bar with curved-in waist, now commonly referred to as a "dovetail" clamp. Clamp types vary in shape: dovetail, double-T (of "dumbbell-shape") sometimes with circular or semicircular heads, straight bar, the alphabet capitals I and H, and butterfly (or "bow tie"). For the material, iron was the most popular, but wood, stone, bronze, lead, and even gold were used (modern retrofitting is done with steel or titanium). Due to their high cost and the demand for skilled craftsmen to produce both the precision cut of clamp grooves and rust-proof metal clamps, these clamping devices were mostly applied to architecture and monuments built under state and religious commissions of the ancient world. Despite their global presence and continuous reports on new findings, the subject has not received serious scholarly attention.[3] This is probably due to the fact that they are mostly found lying buried and thus considered to be ancillary concern. But their common features in form, material, production, and installation seem to imply trans-regional circulation and world-wide adaptation of the technology. Time and again world history proves that the speed of knowledge-travel is much faster than local-level independent inventions in the field of art and technology.

The Western world of the first millennium CE was, it is no exaggeration to say, under the spell of Roman technology and art in stone masonry—as witnessed through Roman roads, aqueducts, amphitheaters, victory gates, colosseums, and arch bridges built everywhere within the far reaches of the Empire. Their stone monuments and architecture were virtually an encyclopedic repository of stone-joint clamps in all possible types and materials. The enduring influence of the Romans even after the fall of Rome was felt strongly throughout the Byzantine East and Sassanian Persia, who in turn were destined to be the transmitter of Roman masonry to the Far East.

In East Asia, as of now, the earliest stone-joint clamps come from China and are datable to the early 6th century CE, followed by Korea in the late 7th century. Finds from India and Southeast Asia date to the 9th-11th century, though some with even earlier dates may eventually surface. Admittedly, a full investigation of the circumstances behind the relatively late arrival and sudden flourishing of clamping technology in China and Korea is beyond the scope of this article. Such an inquiry may lead us into the complex topic of contacts between East and West in the architectural field—an aspect that has been largely neglected in the general Silk Road narrative of transcontinental and transoceanic exchanges and encounters.

By its very nature, this "microstudy" on the subject of stone-joint clamps cannot be conclusive, and

* This is a revised and shortened version of an earlier article that was originally published in two parts. See Kim Hongnam, "Tongil-Silla jeongi Geonchuk ui Eun-jang Yeongu" [On stone-joint metal clamp "eun-jang" from early Unified Silla stone monuments], *Misulsahak Yeongu*, no. 303 (September 2019) and no. 304 (December 2019). A few more sites that came to my attention after publication necessitated some revision, but the main points of the argument remain unchanged.

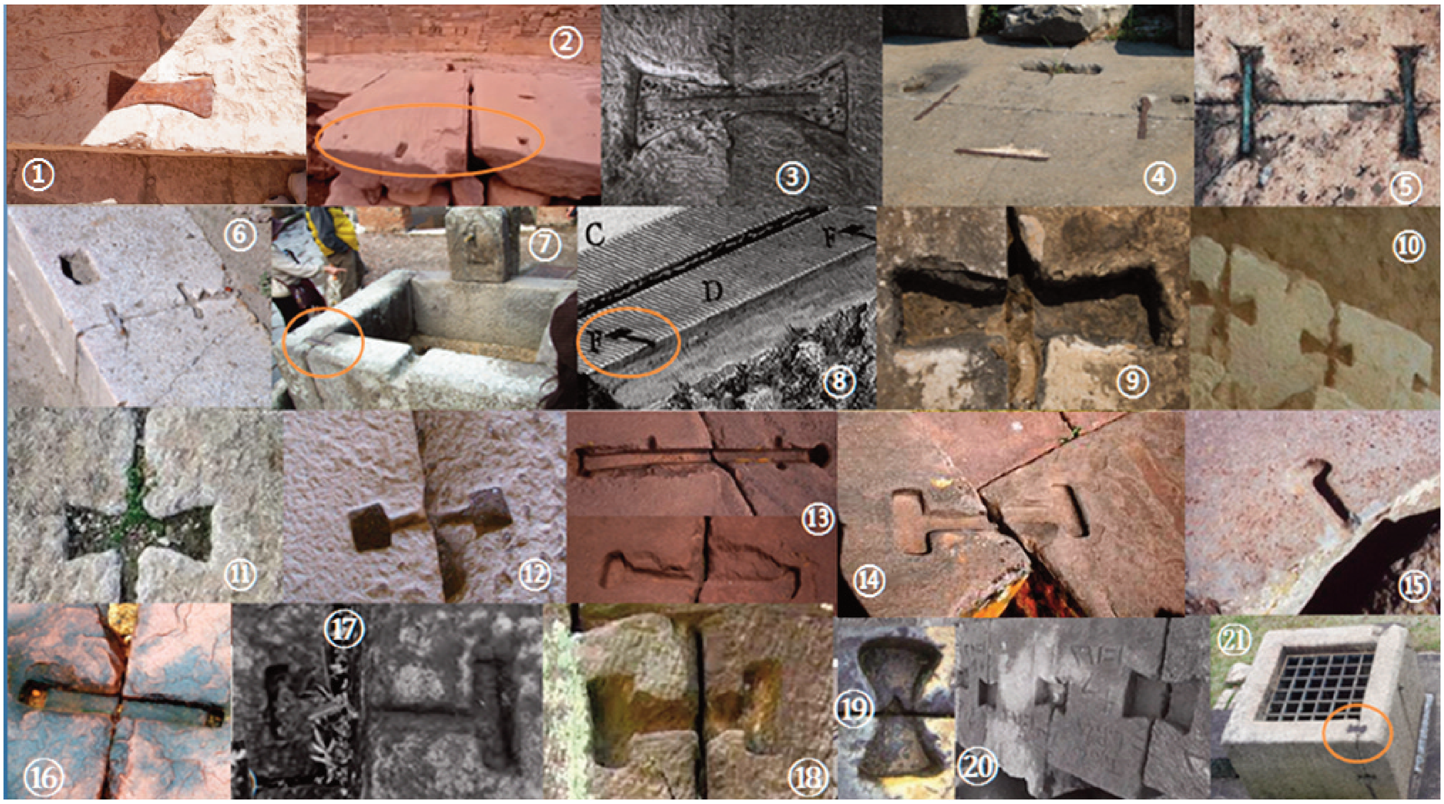


Fig. 1. Examples of stone-joint clamps from around the world: 1) Upper Anubis shrine at the Temple of Hatshepsut, Egypt, Deir El-Bahari, c. 1450 BCE; 2) Theatre at the Acropolis, Greece, 5-4th BCE; 3) Pasagarde, Iran c. 500 BCE; 4) Delphi Temple, Greece, 5th-3rd c. BCE; 5) Oikio Temple, Turkey, mid-4th c. BCE; 6) Roman Forum, Rome, Mid-1st c. BCE; 7) Pompeii, Italy, datable before 79 CE; 8) Aurelian Walls, Rome, 271–275 CE; 9) Artemis Temple, Sardis, Roman Section, 1st-4th c. CE; 10) Tigranakert Roman Ruines, Armenia. 1st c. BCE; 11) Tunisia; 12) Axum, Ethiopia, 3rd-5th c. CE; 13) Puma Punku, Bolivia, pre-Inca; 14) Tiahuanaco, Bolivia, pre-Inca; 15) Tiahuanaco, Bolivia, pre-Inca; 16) Bijamandal Complex, India, pre-13th c. CE; 17) My Son, Vietnam, ca. 10th c. CE; 18) Ankor Wat, Cambodia, ca. 10th c. CE; 19) Angkor Wat, Cambodia, ca. 10th c. CE; 20) Borobudur Indonesia. ca. 9th c. CE; 21) Imperial Palace, Tokyo, Japan, ca. 17th c. CE.

new findings will lead to future revisions. But it is worthwhile to take a step toward understanding the development of East Asian stone masonry. The primary aim of this paper is to introduce the Chinese and Korean stone-joint clamps of the period from the early 6th century to the 8th century through a few representative case studies. First is a survey of the Chinese specimens, with particular attention paid to the Zhaozhou Bridge 趙州橋 of the Sui dynasty 隋朝 (581-618 CE), which represents early Chinese stone architecture above ground with a full-scale application of the device. The second case study will be on Korean specimens found from sites in Gyeongju, the capital of the Unified Silla dynasty 統一新羅 (676-935 CE). Special attention will be given to the Seokguram 石窟庵 Buddhist grottoes of the mid-8th century, which features the true dome architecture of full-fledged ashlar masonry with sophisticated clamping technology.

Stone-joint Metal Clamps from Northern China, 6th-7th Centuries CE

The common Chinese term for stone-joint clamps is *yaotie* 腰鐵 (literally "waist-iron"), a term which first appeared in early 8th century literature to describe the dovetail-type clamps on the Zhaozhou Bridge of the Sui dynasty. According to current knowledge, the earliest known *yaotie* clamps are from the first three decades of the 6th century during the Northern Wei dynasty 北魏朝 (386-534) in the north and the Liang dynasty 梁朝 (502-557) in the south.

The clamps found so far in the north are typologically consistent with the "dovetail" type seen throughout the Tang dynasty 唐朝 (618-906). But in the south a different typology emerges: the clamps are of the dumbbell type with heads in square or circular-shape, which belongs to the category of T-shape in the West. Though limited to only two Southern Liang sites, one appears particularly significant in consideration of its imperial connection with the Liang royal mausoleum in the vicinity of its capital at Nanjing, the cultural center of southern China. This typology, if practiced with consistency, may indicate that the routes of its transmission were different from that of the north; in fact, this would not have been impossible during the period of the Southern and Northern Dynasties 南北朝 (386-589), when China experienced political and cultural divisions between the non-Chinese ruled states of the north and the Chinese-ruled states of the south before reunification under the Sui dynasty at the end of the 6th century.

A Seated Colossal Buddha, Yungang Grottoes

Stone-joint clamps were found in a curious circumstance in cave 19 of the Yungang Grottoes 雲岡石窟 at Datong 大同 in Shanxi 山西 province. Established under the patronage of the Northern Wei court, the grottoes were carved directly into the face of a cliff. The seated colossal Buddha in the cave is one of the five colossal Buddha statues executed in the first period (460-465) of the Yungang project as representations of five early Northern Wei rulers as reincarnations of the Buddha.

Included in a comprehensive report on the Yungang complex that was published by Kyoto University from 1938 to 1945 by Mizuno Seichi and Nagahiro Hoshio are photographs of the grottoes with extensive damage, as if shaken by an earthquake. All images of cave 19 are shown with repair work visible, and is especially prominent on the colossal seated Buddha. These photos of the statue also reveal full-fledged *yaotie,* i.e., iron clamps of dovetail type, to mend heavy cracks on the nose. The application of three dovetail clamps is visible on the damaged nose from the photographs [**Fig. 2**].[4] Obviously these photos were taken before final restoration work; at present, such traces of earlier repair work are no longer visible.

Since the dovetail-type clamps persisted through the Tang dynasty in northern China, the application of clamps and the occurrence of damage must predate Song dynasty. The only pre-Song natural disaster which could have affected the Yungang grottoes to such an extent was the great Shanxi earthquake in the year 512 (two later Shanxi earthquakes in 1303 and 1556 are thus not applicable). The 512 earthquake, which was of 7.5 magnitude, shook northern Shanxi, including the Datong area, and took lives of more than 5,300 people. Considering their symbolic importance to the Northern Wei dynasty, the grottoes—and in particular the five colossal Buddha statues—were probably repaired before the dynastic fall in 534. Thus the clamping work on the broken nose can be dated to sometime between the earthquake in 512 and the

Fig. 2. Left: Seated Colossal Buddha, Cave 19, 460-465, Northern Wei. Yungang Grotto, Datong, Shanxi, China; Right: Repair work (sometime between 512-534) of the cracked nose with dovetail-type iron clamps.

fall of the dynasty in 534. This marks some of the earliest evidence for the use of stone-joint clamps.

Yungang, a great Buddhist monument in northern China, was a melting pot of art and technology from across Eurasia and India. It also demonstrated the adoption of the Indian rock-cut cave tradition along with Hindu iconography and the use of Persian and Central Asian motifs and decorative style. Many artists who worked for the Northern Wei at sites such as Yungang likely came from or were trained by artisans from Central Asia and perhaps even further West, among whom were quite possibly migrant stonemasons and blacksmiths skilled in ashlar masonry and clamping technique. In fact, the Northern Wei rulers of Toba-Xianbei lineage originally came from the Eurasian steppe and were known for their receptivity to outside cultural and technological influences. Ultimately, they fostered a new type of cosmopolitanism in northern China during the 5th and 6th centuries, which would be inherited by the Sui and Tang dynasties.

Although clamping devices were not applied to the living-rock grottoes of Yungang, the ready application of the *yaotie* device for the aforementioned repair work is indicative of its circulation in cut-stone masonry architectural circles by the early 6th century in north China. This finding is also supported by a stone foundation reinforced with the same dovetail-type clamp that was found at the Northern Wei imperial cemetery in Luoyang, which is discussed in the next section.

Fig. 3. Top: Excavation site of a Northern Wei imperial tomb (ca. 525-534), Luoyang. Bottom: A stone block from the wall foundation, with evidence of a dovetail-type clamp-groove.

The Stone Wall Foundation at a Northern Wei Imperial Tomb, Luoyang

Another early evidence for the use of *yaotie* clamps comes from an imperial tomb of the Northern Wei dynasty that was excavated in 2013 in Luoyang 洛阳, the last of its dynastic capitals. The excavation received extensive coverage in the *Loyang News* 洛阳新闻, including a full interview with Dr. Liu Bin 刘斌, the scholar in charge of the excavation who is affiliated with the Luoyang Institute of Cultural Relics and Archaeology.[5] This large underground tomb has been dated to 525-534 CE, based upon some burial goods left by grave robbers; among them is a Byzantine gold coin of Anastasius I minted between 491 to 518 CE. Emperor Min 闵帝 (498-532) is most likely the owner of the tomb.

Now in a state of ruin, the tomb is about 58.9 meters long and consists of two long slopes (front and rear) leading to a single chamber (19.2 x 12 x 8.1 meters). Built mostly with stone-bricks covered with soil (rammed earth), the tomb reveals the use of large cut-stone blocks for both the entrance and the wall foundation, which are considered rare and unique for Northern Wei tombs and provide new evidence for the development of ashlar masonry. Left of the wall foundation is a single stone block bearing the clear mark of a clamping device with one half of a dovetail-clamp groove, which Liu Bin describes as "an inverted triangle groove" [**Fig. 3**]. Evidently the foundation was constructed of cut-stone blocks bound by stone-joint clamps. This is a significant find of the clamping device for the first time in architectural context.

In view of recent scholarship on the mobility of nomads and steppe people and their exchanges with the Byzantine West and Sassanian Persia, contacts with the Northern Wei could have occurred even earlier when the dynastic capital was in Yecheng 鄴城 or Datong 大同, or even before their dynastic rise in the Eurasian steppe.[6] In fact, the traces of clamp technology at both the grottoes of Yungang and this imperial tomb site in Luoyang can be taken as evidence for the development of cut-stone architecture in northern China, most likely with stimuli from the Roman masonry built in Byzantine Rome and Sassanian Persia.

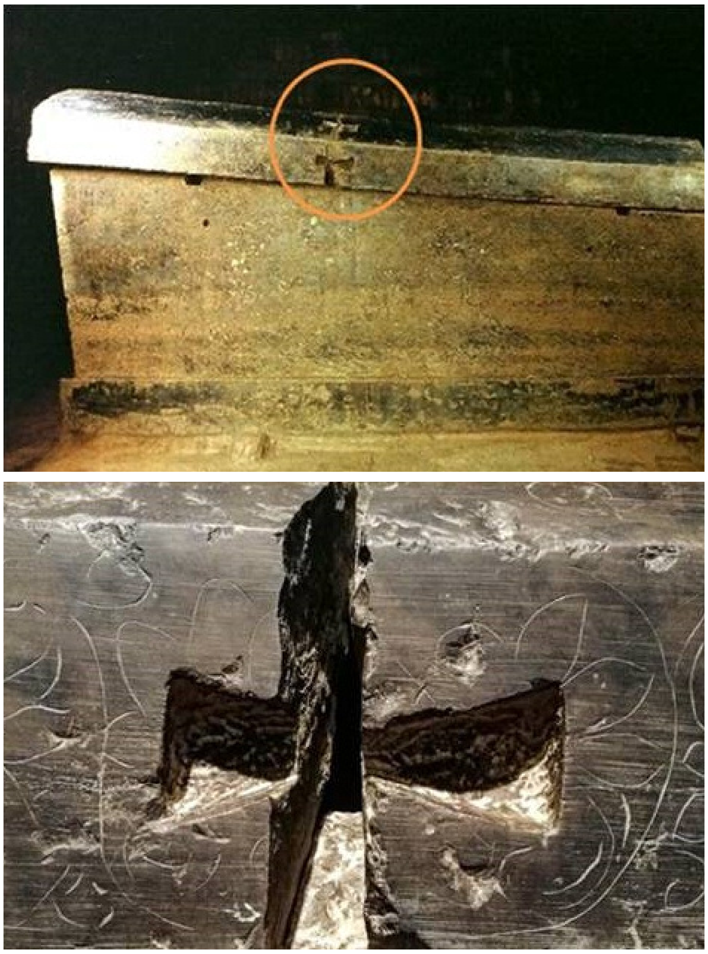


Fig. 4. Top: Stone casket from the tomb of Li Dan (d. 564), Northern Zhou, Xi'an, Shaanxi, Xi'an City Museum; Bottom: Detail of dovetail-type clamp-groove.

Stone Mortuary Furnishings of the Northern Zhou and Sui Periods

From the period following the Northern Wei until the time of the Zhaozhou Bridge at the turn of 7^{th} century, *yaotie* clamps appear on some of the stone coffins from tombs in the northern Chinese provinces of Gansu, Shaanxi, Shanxi, Henan, and Shandong. The tomb occupants have been identified as foreign immigrants mostly from Sogdiana, with some from Sassanian Persia and northern India.[7] Related archaeological reports and a good many studies on these coffins in the collection of Chinese and overseas museums rarely scrutinize aspects of masonry and crafting technique. Therefore, this survey must rely on the occasional reference to the presence of *yaotie* clamps, though the number of cases may increase in the future.

To be discussed below are five stone coffins with *yaotie* devices, which date from the middle of the 6^{th} to the early 7^{th} centuries. Included are one casket type from the tomb of Li Dan 李誕, two house-type sarcophagi from the tombs of Shijun 史君 and Li Jingxun 李静訓, and two screened couch-type from the Vahid Kooros collection (Texas, USA) and from an unidentified tomb excavated in Tianshui 天水 (Gansu Province).

The tomb of Li Dan 李誕 (d. 564 CE), excavated in 2005, is one of the Northern Zhou 北周 (557-581) era tombs that was excavated in the Xi'an 西安 area of Shaanxi province [**Fig. 4**].[8] Li was a first-generation immigrant of Indo-Brahman descent who was originally from the Kabul-Kashmir region. He and his wife were interred in one large Chinese-style stone casket decorated with incised images of traditional Chinese themes (e.g., Fuxi and Nüwa and the four directional symbols) and with a trace of a *yaotie* clamp device on its lid. The casket measures 2.37 meters long with its raised front 1.2 meters in height. The lid, made of a single stone, shows a split developed from the edge of one side with two sets of deeply cut grooves crossing over the split. The grooves are clearly shaped for dovetail-type clamps. The crack positioned at its inflection-weight point and the application of a *yaotie* clamp crossing *over* the incised decoration together indicate an accidental cracking that probably occurred when the lid was lifted for an additional interment, which in turn required the application of a clamp to prevent further split.

The tomb of Shijun 史君 (Master Shi, d. 579 CE), excavated in 2003 in Xi'an, yielded a stone sarcophagus that was modeled after a traditional Chinese house. It is assembled of stone blocks, for which stone-joint clamps were used [**Fig. 5**]. A bilingual epitaph, located on the lintel, reveals that the occupants of the tomb were Shijun (whose Sogdian name was Wirkak) and his wife Wiyusīa, and that they were an elite Sogdian couple from Samarkand who lived in Xi'an. Shijun served as a *sabao* 薩保 in

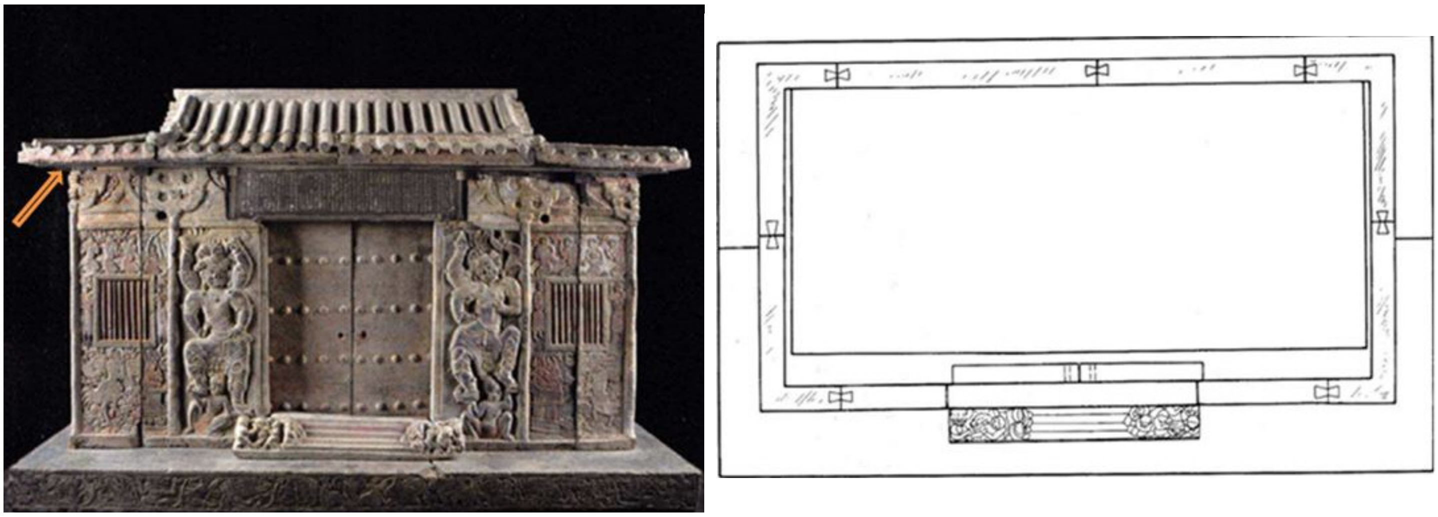


Fig. 5. Left: House-type sarcophagus from the tomb of Shijun (d. 579), Northern Zhou, Xi'an, Shaanxi, Xi'an City Museum; Right: Drawing of (dovetail?) clamps on top of wall panels.

Liangzhou 涼州 (present-day Wuwei, Gansu).[9] Liangzhou was a once-booming hub of international trade on the Silk Road and an important stopover and stronghold of the Sogdians. A *sabao,* meaning "caravan leader," was the title for a head administrator of the foreign communities in China.

This sarcophagus is an assembly of stone blocks sculpted and carved in imitation of a timber-framed Chinese house or temple with a hip-and-gable roof. Consisting of a base, a middle section, and a roof top, the sarcophagus measures 2.46 meters in length, 1.55 meters in width, and 1.58 meters in height. The "Drawing of the Mortise-Tenon Joints for the Stone House" 石堂榫卯結構圖 from an archaeological report shows seven sets of clamps used to bind the eight stone-slabs which made up the wall for the middle section.[10] The clamps are described in the report as follows: "The 'slender-waist' 細腰 in iron measures 8 centimeters in total length, its head 4 centimeters in width, its waist 2 centimeters in width. It is also called *yinding sun* 銀錠榫 ('silver-ingot tenon')." Without any photos available it is difficult to identify the clamp type based on the drawing alone, and speculation is made even more difficult by the use of terminology in the description that is more applicable to carpentry. But in the light of all circumstances prevailing at that time, it is most likely the dovetail type.[11]

Another house-type sarcophagus with the *yaotie* clamp device is from the tomb of Li Jingxun 李静訓墓 (d. 608), which was excavated in 1957 in Xi'an [**Fig. 6**].[12] Li, who passed away at the tender age of nine, was from an aristocratic Sui family of mixed Han Chinese/Yuwen-Xuanbei descent. Popularly called the "Tomb of Child Li" 李小孙墓, it contained a small house-type sarcophagus (1.92 meters long, 1.61 meters tall, 0.89 meters wide) filled with lavish offerings consisting mostly of foreign imports such as necklaces and bracelets (made in a "Persian-style"), along with a Persian coin. The sarcophagus is

Fig. 6. Left: House-type sarcophagus, tomb of of Li Jingxun (d. 608), Xi'an, Shaanxi, Sui, Xi'an Beilin Museum; Right: Lower part of the inner coffin with dovetail-type clamps.

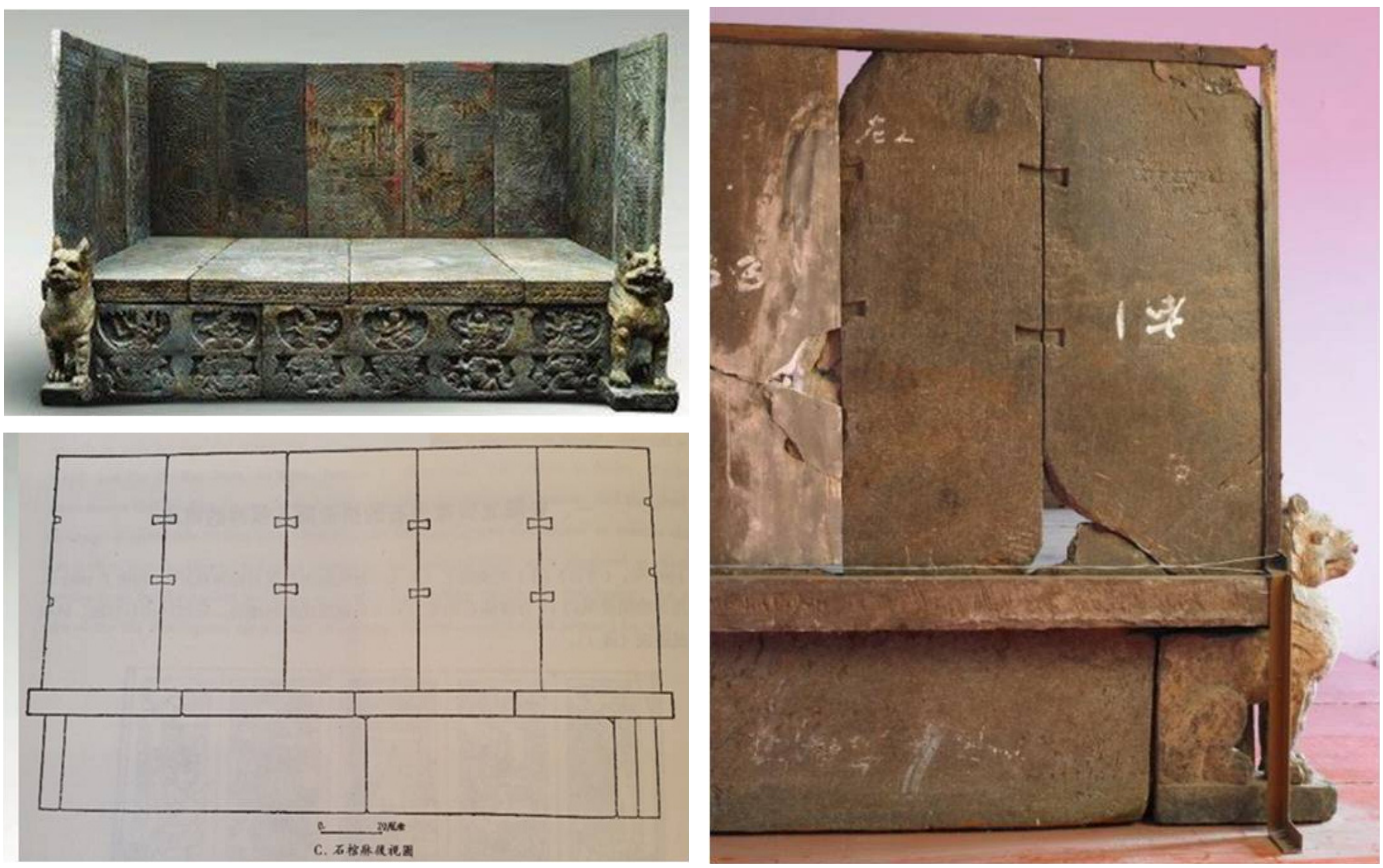
constructed of 17 blocks of stone in total. The wall consists of six stone blocks joined on top by six iron clamps of the dovetail type. It is also mentioned in the report that more clamps were found in other parts of the sarcophagus.

There are a number of stone funerary couches enclosed by a screen of stone panels with the front open; most of them were excavated from tombs that date from the 6^{th} to early 7^{th} centuries, but some appeared in the art market without provenance and ended up in the museums and private collections abroad. These couch-type coffins, the most sumptuous among the stone coffins of the period, have fascinated many scholars with their Eurasian connections as well as the rich art historical contents.[13] As of now, only two have been determined to feature a *yaotie* clamp to secure the stone screen panels. But due to the instability of the tall screen panels in perpendicular set-up on the edge of the bed, most of these types of coffins probably resorted to the same sort of clamping device, even if they were also locked into the bed-stones below by the tenon-joint method.[14]

One screened funerary couch is from a late 6^{th}-century tomb of an unidentified occupant that was excavated in 1982 in Tianshui, Gansu province [**Fig. 7**].[15] The couch is screened on three sides by 11 stone panels (five back panels, six side panels) embellished with gilded and painted relief images. Although this type of screened couch appeared as early as the 4th century in Chinese depictions of everyday life scenes, the pictorial imagery also includes Near Eastern/Central Asian iconography. These panels (each measuring in average 0.87 meters in height and 30-46 centimeters in width) are tied up by two pairs of dovetail *yaotie* clamps on the back. Now only empty grooves are left in shape to fit clamps measuring approximately 8 centimeters in length, 3-4 centimeters in width (for the head), and 1 centimeter in thickness.

Another screened funerary couch is popularly known as the "Kooros Bed," which is held in the Vahid Kooros collection but used to be on loan at the Musée Guimet, Paris [**Fig. 8**].[16] Based on its overall similarity to the aforementioned couch, it is assumed to have been from the area of Tianshui.

Fig. 7. Left top: Screened-couch type coffin, excavated in Tianshui, Gansu. late 6th–early 7th c., Northern Zhou-Sui, Tianshui City Museum; Left bottom: Drawing of the back of the coffin with clamps marked; Right: Detail of the back of the coffin with dovetail-type clamp-grooves.



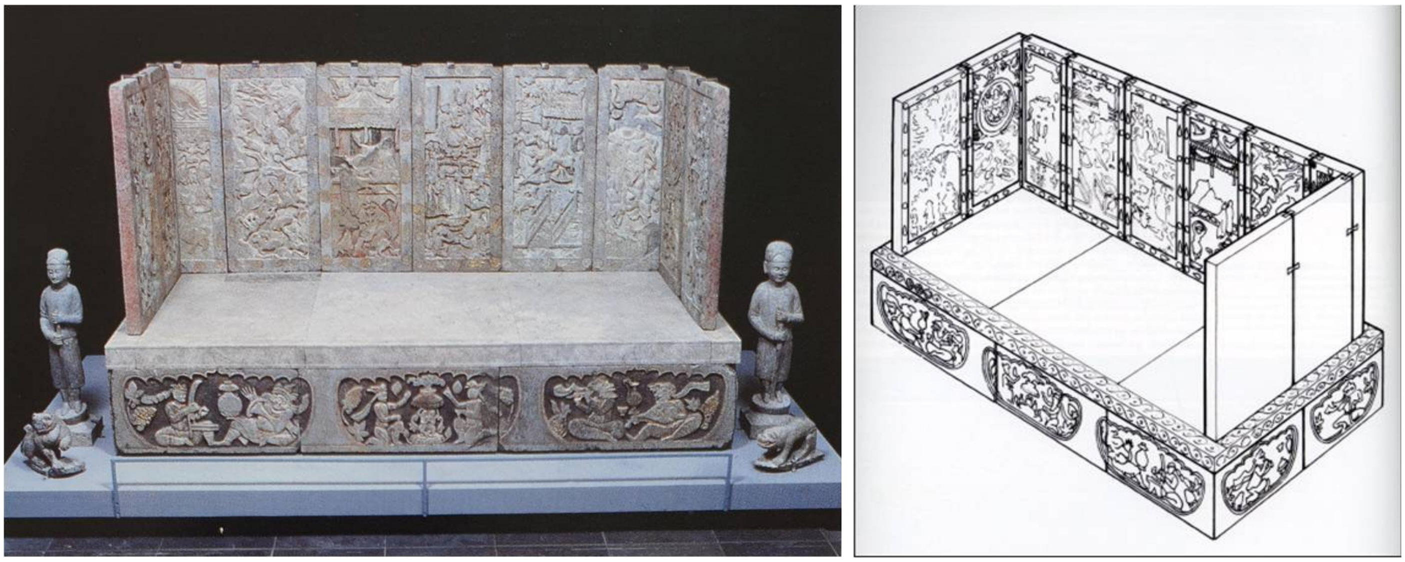


Fig. 8. Left: Screened-couch type coffin, probably from Tianshui, Gansu, late 6th–early 7th c., Northern Zhou-Sui. Vahid Korooso Collection, Texas, USA; Right: Reconstructed drawing of the couch showing dovetail-type clamps on the back and top of the screen panels.

The iconography of the pictorial imagery and stylistic features of both couch coffins give enough evidence to conclude that their occupants came from the border regions of the Indian domain, either from Bactria or from Gandhāra. According to drawings of the reconstructed Koroos bed, the screen consists of 10 stone panels (six on the back and four on the sides) joined by 18 clamps (nine on the back and nine on the top). They are undoubtedly grooves meant for dovetail-type clamps.

Stone-joint metal clamping required individuals who were skilled in both stone masonry and metal-forging for their production and installation. Apparently, the aforementioned tombs mostly belonged to members of thriving communities of foreign immigrants who were capable of underwriting such a costly undertaking as mobilizing a skilled work force for the production and repair work of coffins. Could such communities of westward connections in northern China have attracted and nurtured stonemasons and blacksmiths of Western origin? Furthermore, northern China at the time was under the rule of highly cosmopolitan Inner Asian nomadic peoples who fostered a society receptive of foreign culture and technology. This receptiveness was sustained through the Sui and the mid-Tang until the 755 rebellion of An Lushan (a military commander of Sogdian-Turk descent), which instigated an anti-foreign policy. The emergence of the world-renowned Zhaozhou Bridge at the turn of the 7th century, discussed below, should be understood against such a historical backdrop.

The Zhaozhou Bridge of the Sui Period

The Zhaozhou Bridge 趙州橋 (officially named Anji Bridge 安濟橋) is a stone arch bridge of the Sui period (581-618), which crosses the Xiaohe 洨河 river south of today's Zhaoxian 趙縣 county (once a part of Zhaozhou 趙州 in ancient times) in Hebei province. The Xiaohe flows into the Fuyang River via the provincial capital city Shijiazhuang 石家庄 [**Fig. 9**].[17] The bridge is also popularly called the "Greater Stone Bridge" 大石橋, in contrast to the smaller Yongtong Bridge 永通橋 nearby, which is known as the "Lesser Stone Bridge." Having been much damaged with the water nearly dried up, the bridge was in disuse and forgotten about until it was "rediscovered" by Liang Sicheng 梁思成, the distinguished Chinese architect and historian of architecture. Liang was instrumental in drawing domestic and international attention to its historical importance and beauty, which eventually led to its major restoration in 1952-56.[18]

The Zhaozhou Bridge's earliest record comes from the "Encomium on the Stone Bridge with a Preface" <石橋銘幷序>, which was written in in the 720s by Zhang Jiazhen 張嘉貞 (665-729). In it, Zhang gives the Sui-dynasty date for the bridge and uses the words *yao* and *tie* for the first time.[19] Embedded in the phrase "waist-slender iron" 腰纖

鐵, the words are used to describe the iron clamps on the bridge, with a curved-in waist commonly referred to as a “dovetail” type in the West and a “swallowtail” type in China. With its exuberant dovetail *yaotie* clamps on the surface of the arch stones, the bridge spawned the popular name “Anjiqiao-style *yaotie*” and became regarded as the *yaotie* type-site.

The Zhaozhou Bridge is a single, segmental-arch bridge (1/4 arch-segment, arc of 84 degrees) with four open-spandrels on the shoulders of the main arch. It measures 64.4 meters in total length and 9.0-9.6 meters in width, with an actual arch-span of 37 meters. Free of piers, the bridge’s entire structure and total weight of 2,800 tons are supported by 28 rows of arch stones, including the two outermost rows and the abutments on both shores. It has enjoyed fame for the longest single-arch span in the world. But little attention has been given to the remarkable presence of stone-joint iron clamps, so prominently visible on the perpendicular surface of the main arch and spandrel arches. Its 240 clamps (visible in situ) seem to have functioned not only as a reinforcement device for the arch structure, but also as an integral part of the design to enliven and enrich the beauty of the stone arches.

The 240 clamps are mostly installed in sets of two to join every two arch stones on the main arch, except where a set of 3 clamps is applied to join the regular arch stones with a demon-faced (辟邪用鬼面) keystone. But the spandrel arch-stones are joined by a single *yaotie*. All are dovetail-type iron clamps, identical in form and size. Each one measures approximately 34 centimeters long, 20 centimeters wide (of head), and 8 centimeters in thickness. Installing iron clamps on a perpendicular surface meant that the clamps had to be precast and inlaid in the prepared cut-grooves with extreme precision, rather than pouring liquid-iron into grooves from a portable furnace. In addition to the clamps, other structural reinforcement devices include iron tie-bars (trans-piercing the 28 rows of arch stones with only their heads visible), stone-rivets, and keystones, all reminiscent of Roman (West and East) architecture and stone bridges.[20] At the same time the bridge expresses Chinese culture and aesthetics through its design of sculpted rails and vigorous relief sculptures full of traditional Chinese symbolism. The dovetail clamps dotting the arch surface have even been interpreted as resembling “the scales of a dragon” (to bor-

Fig. 9. Top: Zhaozhou Bridge, ca. 600, Sui era, Zhao County, Hebei; Bottom left: Details of dovetail-type clamps (head of the iron tie-bar is circled, while an arrow points to a stone-rivet); Bottom-right: close-up of metal joint clamp.

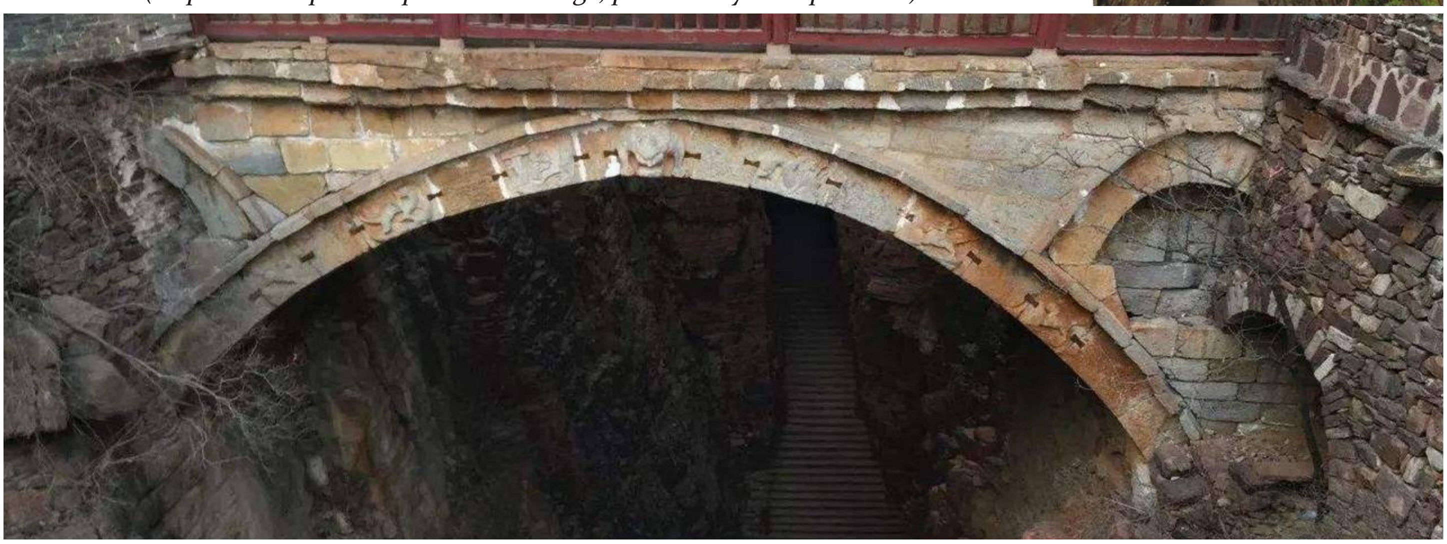
Fig. 10. Left: Yongtong Bridge (open-spandrel segmental arch bridge), ca. 7-8th c., Zhao County, Hebei; Right: details of dovetail-type iron clamps.

row a Chinese description).

Technically, the Zhaozhou Bridge can be interpreted as a creative adoption of one segment of a Roman-style multi-pier arch bridge built over narrow waters with the omission of piers. This made it possible to avoid constructing piers against the continuous force of the flowing water. The omission of piers, the long extension of arch span, and the additional spandrel openings served several purposes. They allowed inundating water to escape without damaging the bridge and decreased overall weight stress, ultimately contributing to its incredible longevity.

Soon after its completion, the Zhaozhou Bridge became a celebrated cultural symbol of the Hebei region. A number of bridges built in the style of the Zhaozhou Bridge sprang up in the region with the same inlay application of dovetail *yaotie* on exposed perpendicular surfaces. They are best represented by the above-mentioned Yongtong Bridge 永通橋 and the Qiaolou Dian 桥楼殿 stone bridge in the Xuankongsi temple 懸空寺 on Mount Cangyan 蒼岩山 (located southwest of Shijiazhuang city) [**Figs. 10, 11**].[21] Significantly, it seems that, beginning with the Zhaozhou Bridge, the stone-joint clamps, no longer ancillary, claim their own importance. Though very rare, such exposed

Fig. 11. Above: Qiaolou Dian stone bridge, ca. 7th c. at Xuankongsi Temple, Mount Cangyan, Shijiazhuang, Hebei; Below: Dovetail-type clamps along the span of the segmental arch. (Haphazard repairs impaired the bridge, particularly two spandrels) .



perpendicular inlay-application of clamps—with similar aesthetic intention—is noticeable at some Roman and Roman-influenced architecture. These include the Colosseum (completed in 80 CE) of Rome and the "Mihr Narseh" bridge (early 5th c. CE) now in ruin in Firuzabad Iran.[22]

No one would doubt the Zhaozhou Bridge was a product of the best science, technology, and artistry in stone arch architecture of its day. So extraordinary was it that a folk legend grew up around its construction: it was said that Lu Ban 魯班, an engineer, inventor, and carpenter from the 5th c. BCE and the patron deity of builders, miraculously built the bridge overnight. Even more than a century after its construction, Zhang himself exclaims in his "Encomium" that "its construction is too mysterious and unusual for the people to understand how it became possible" (製造奇特, 人不知其所以).

In the same writing, however, Zhang also refers to a man named Li Chun 李春 who he claims was responsible for the construction of the bridge: "The stone bridge on the Xiaohe of Zhaojun county is a legacy of the Sui-period master craftsman Li Chun" (趙郡洨河石橋，隋匠李春之跡也). This terse account is aided by the only other biographical information, given in a footnote by his grandson, that Li Chun was from Yaocheng village 堯城鎮 (present Longyao xian, Xingtai City 邢台市隆堯縣) in Hebei.[23] It seems that the identification of Li Chun is key to the secret of the construction of the Zhaozhou Bridge. But Li's name has never reappeared in other historical literature, and he later became a quasi-historical figure inseparable from the bridge (he is now honored with a large statue at the site park).

The naming of Li Chun offers a tantalizing insight into the existence of communities of stonemasons and blacksmiths, possibly of foreign origin and including recent newcomers, in the area surrounding the Zhaozhou Bridge. In fact, the region includes the cities of Shijiazhuang 石家庄 (literally meaning "Stonemason's Lodge") and Xingtai (particularly Yaoshan 堯山), both historically famed for rich mineral deposits and quarries that would have attracted communities of skilled stonemasons and stone craftsmen. They in turn would have provided the workforce and material for the Zhaozhou Bridge.

Certainly, northern China was a nourishing ground for the emergence of outstanding architects and stonemasons—be they native, sinicized nomads, or Western foreigners. Yuwen Kai 宇文愷 (555-612), for instance, who was descended from a Yuwen-Xianbei elite family of nomadic origin, was the Sui court's principal architect and its most celebrated. Li Chun, though his identity has not been historically verified, was most likely the master-builder for the Zhaozhou Bridge and was probably proficient in Roman arch bridge technology.[24]

Obviously, we are still left with an insufficient understanding of how such a bridge, equal to or perhaps even surpassing the best of Roman bridges, came into being at this particular time and at a place far from any metropolitan centers of the day. But from a broader perspective, the Zhaozhou Bridge was unquestionably a manifestation of the cosmopolitan culture of the Northern Dynasties and the culmination of a great synthesis of Eastern and Western stone architecture and arch bridge technology and culture.

Stone-joint Metal Clamps from Southern China, 6th Century CE

Little information has been available for the southern Chinese stone masonry and stone-joint clamps prior to the Song dynasty (960-1279). Therefore it was quite unexpected to find traces of clamps from sites in the lower Yangtze region, which was the political and cultural arena of the Southern Dynasties. Even more surprising is that they seem to present a picture much different from that seen in northern China, though it would be premature at this point to jump to conclusions based on such a small data sample. Nevertheless, they provide new evidence for the development of stone masonry art and architecture under the Southern Dynasties in the period of North-South division.

One find is from a site labeled as "Stone Carvings for the Mausoleums of the Southern Dynasties in Danyang" 丹陽南朝 陵墓石刻, which is located not far from the Liang dynasty (502-557) capital of Nanjing in Jiangsu province.[25] The site is full of animal guardians and memorial steles, mostly in poor condition and half-buried around paddy

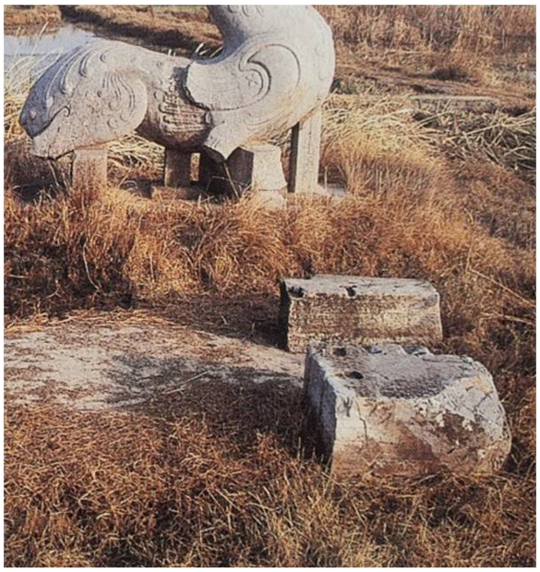


Fig. 12. Left: Stone-blocks with dumbbell-type clamps with circular (or square) heads, Jianling mausoleum of Emperor Wen, Liang dynasty, early 6th c., Danyang (near Nanjing), Jiangsu; Right: A sample block.

fields. They originally lined up alongside a spirit road that led to ten imperial mausoleums for the emperors of the Qi 齊 (479–502) and Liang 梁 dynasties and their family members.

The square cut-stone blocks with traces of clamps are found lying on the ground of the Jianling Mausoleum 建陵, which was built posthumously for Emperor Wen 文帝 (Xiao Shunzhi 蕭順之) of Liang by his son Emperor Wu 武帝 (r. 502-549), the dynastic founder [**Fig. 12**]. All stone blocks show two inner sides, each of which bears one half of a clamp groove indicating that the blocks were part of an assembly of four or six stone blocks. These blocks served as a stone base for either a guardian-animal sculpture (mostly measuring longer than 3 meters and taller than 2 meters) or a tall stone stele. Though the grooves are clearly formed to fit the dumbbell-type clamp, the shape of the heads is unclear since they were smudged when the metal clamps were extracted by force. They might have been rectangular, circular, or semicircular. But they are clearly distinguishable from the dovetail type clamp that prevailed in contemporary northern China.

The same type of clamp groove, this time clearly with a circular head, is also spotted from the pier stones of the Yicheng Bridge 义成桥 in Gourong city 句容市 (just south of Nanjing) in Jiangsu province [**Fig. 13**].[26] Although the upper structure of the present bridge is a late Qing reconstruction, the streamlined piers seem to have kept some of the old pier stones, which most likely date from

Fig. 13. Left: Yicheng Bridge; Right: Pier-stones with dumbbell-type clamps with circular head, Gourong City, Jiangsu. The pier-stones date from the Southern Dynasties (420-589), but the bridge is mostly late Qing reconstruction.

the period of Southern Dynasties.

If the north-south difference in clamping typology can be supported by more cases, serious questions would rise as to which route of transmission was taken by the southern clamps, which are distinct from the dovetail clamps of contemporary northern China not only in typology but also in application method. Worthy of note is the assembly of stone blocks with a "hidden" clamp device for large stone bases and for the piers of the stone bridge. This inquiry can be also extended to the Korean clamps of the late 7th-8th centuries, which, though more than a century later, curiously show similarities in both typology and application method.

The Liang royals and Han Chinese elites were the fountainhead of southern Chinese culture and Buddhist religion. Emperor Wu is known for his "excessive" construction of as many as six hundred Buddhist temples, which may indicate Liang contacts with India and South Asia along the "Buddha Road," a part of the maritime Silk Road. In this regard the role played by Jingzhou 荆州 of Hubei 湖北 province was important on the "Buddha Road" as the main gateway to the capital Nanjing, just as Dunhuang of Gansu province played a similar role on the overland Silk Road to Xi'an in northern China.

The central position of the Liang court in the international arena is well illustrated by "The Tribute Bearers" 職貢圖, a painting attributed to Xiao Yi 蕭繹 (508-554, Emperor Yuan, a son of Emperor Wu), a late copy of which is in the collection of the Nanjing Museum. The list of tribute bearers is extensive and partially overlaps with the international contacts of the Northern Wei such as Persia, Central Asia, and India. But also notable is the inclusion of states from the Sichuan basin and some Southeast Asian states (from Malay and west Indochina) as well as from Korea (Baekjae kingdom) and the Wa state (倭國) of ancient Japan. All this historical background may become more meaningful when more specimens surface in the south.

An Overview of Stone-Joint Metal Clamps in Korea, 7th-8th Century

The general term used in Korea for the stone-joint clamping device is *eun-jang* 隱藏 (literally "hidden-stored away"), an apt description of its hidden presence and the fact that it can be seen when the structures are dismantled. Korean clamps of this period are found from stone monuments and sites that are constructed out of cut-stone blocks in dry method. They are all located in Gyeongju 慶州, the capital of the Unified Silla dynasty 統一新羅 (676-935).

Korean *eun-jang* clamps resemble flattened dumbbells with two different shapes of heads: one with square heads in the general category of "T" type (also called "double T") and the other with half-circle heads. Thus in typology they differ significantly from the dovetail-type clamp of contemporary northern China, yet still show a curious affinity to the clamp types of the Liang dynasty in southern China. Since the southern Liang court maintained close ties—political, cultural, and religious—with the Baekjae kingdom independent of the other two of the Three Kingdoms (Silla and Goguryeo), this type of clamp could have been initially introduced to the Korean peninsula through the Baekjae kingdom. But as of now there has been no supportive evidence directly coming from the sites of the Baekjae period.[27]

This survey of Korean *eun-jang* clamps is focused on a selection of stone masonry sites of unquestionable provenance. It begins with the twin stone pagodas of Gameun-sa temple, a royal temple completed in 682 soon after the unification of the Three Kingdoms. The clamps found on the pagodas belong to the dumbbell type with square-heads. This Gameun-sa type clamp gained popularity in the following decades. But by the mid-8th century it was replaced by a clamp type with a 'half-circle' head, which is best exemplified by the Seokga-tap pagoda of the Bulguk-sa temple and the Seokguram Buddhist temple, both built in the reign of King Gyeongdeok (r. 742-765 CE) when the Unified Silla culture and masonry art reached their apex. The "half-circle" type remained popular through the end of the century.

During all this time, the use of metal clamps in Silla was limited to state-initiated stone monuments in the capital area. By the end of the 8th century, the *eun-jang* device gradually became an obsolete technology due to the overall reduction of scale and expense for stone constructions, which in

Fig. 14a. Left: Twin three-story stone pagodas, completed in 682, Unified Silla Dynasty, Gameun-sa, Gyeongju, Korea (the western pagoda in front, eastern pagoda in back). Right top: Exposed clamps on the topmost roof-stone of the eastern pagoda; Right bottom: Extracting a clamp (square-headed dumbbell type) from the western pagoda.

turn was most likely caused by the weakening of royal patronage and by the privatization and regionalization of religious and civil projects.

The Twin Three-Story Stone Pagodas at the Gameun-sa Temple Site

The Gameun-sa site is nestled on a low hill not far from the eastern seashore of Gyeongju, where lies the "underwater tomb" of King Munmu 文武王 (r. 661-81), who initiated the construction of the temple soon after he succeeded in unifying the Three Kingdoms in 676 CE. It was posthumously completed in 682 CE by his son, Kim Sinmun 神文王 (r. 681-92), who named it Gameun-sa ("Temple of Gratitude" 感恩寺) to express thanks for the protection of the Buddha and commemorate his father.[28] What is left of the complex today are the two majestic stone pagodas, skeletal remains of the stone-foundations for the main buildings and surrounding corridor, and traces of the stone retainment wall on the slopes by the central approach. Pagodas, which developed from Indian stupas, had become prominent Buddhist monuments that were used for enshrining sacred relics in all Buddhist nations by this time. The dazzling relics uncovered from these pagodas are listed as national treasures along with the pagodas themselves.

The two pagodas are nearly identical in style and size. They follow a square plan, each measuring approximately 13.9 meters in height and 8 square meters for the bottommost base. The three main components, successfully receding upward like a soaring spire, consist of the following: a two-tiered base assembled of 44 stone blocks, a three-story main body with three in-between roof stones totaling 13 stones, and a topmost vertical iron-rod finial (originally embellished with symbolic jewels) supported by one small-size base-stone [**Fig. 14a**]. A total of 82 ashlar blocks of tuff-rock were used.[29]

Prior to the Gameun-sa pagodas, there existed

Fig. 14b. Left: Installation condition of four clamps on a four stone-block assembly; Center: four extracted clamps from the second level of the eastern pagoda; Right: Clamp-groove (square-head type) from topmost roof-stone of the western pagoda.

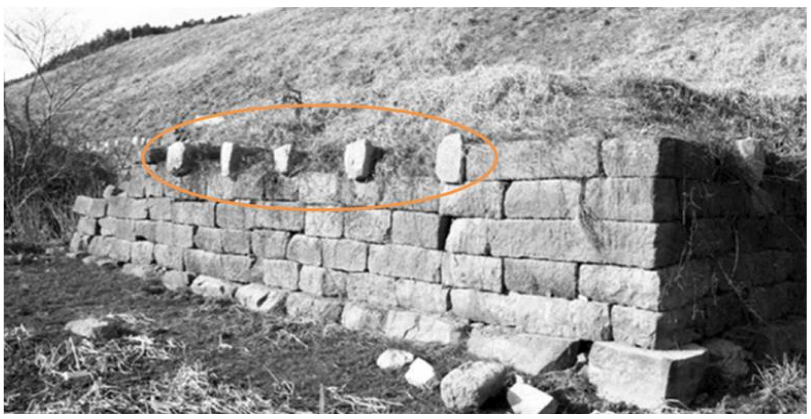
three earlier stone pagodas that were erected in the Baekjae kingdom before its fall in 660. These include the Miruk-sa and Jeongrim-sa temples. Regarded as the prototype of stone pagodas in Korea, they are close imitations of wooden pagodas but were constructed with cut-stones (up to more than 2,000 for each of the Miruk-sa pagodas) sculpted in close proximity to the timber components for both interlocking and groove joints. Consequently, these Baekjae pagodas had no actual need of stone-joint clamps.[30] On the other hand, the Gameun-sa pagodas were assembled out of large cut-stone blocks with mostly flat-surface finish without mortar. This necessitated resort to the *eun-jang* clamping method to bind them for structural stability. The result was a drastic reduction of the number of stone blocks (down to only 82), a remarkable change from the Baekjae-type pagodas. Nevertheless, the Gameun-sa pagodas are regarded as belonging to a transitional phase since they retain certain features of the Baekjae wooden pagodas. These include the stone-blocks for the central and the corner pillars, which were carved for interlocking and groove jointing; the gently sloping eaves; and the everted corner of roof stones.

When dismantled for repair work on the western pagoda in 1959-1960, it was confirmed that as many as 58 *eun-jangs* were installed horizontally at all levels (16 *eun-jangs* were used for the two-tier base stones) and the same number assumed for its eastern pair.[31] Exceptional is a set of four *eun-jangs* exposed on the topmost roof (assembled of four separate stone blocks), which has no more stone structure above to "hide" them.

All *eun-jangs* are equally of the "square-head" type, measuring approximately 42-48.5 centimeters in length with a head of 4.5 centimeters in width; the fine-earth fillers were found in some *eun-jang* grooves [**Fig. 14b**]. According to a scientific ferrous-component analysis, they are rust-proof, cast-iron clamps of 82-99% purity. To reach such a level of purity from iron ore is not an easy task even by today's standard. The high level of iron-smelting technology achieved at the time can be assessed by the fact that the iron finial of 3.9 meters, exposed to weather for more than 1,200 years, could be reinstalled after only minor conservation work.[32]

The *eun-jang* installation required a knowledge of structural dynamics since it necessitated the positioning of *eun-jang* grooves on the exact center of forces exerted on cut-stone blocks at each level of multi-storied pagoda. The lifting of heavy stones to a height of more than 10 meters and their placement aligned with matching grooves were another challenge that relied on a rudimentary pulley mechanism and manpower. The whole process would have required expert supervision and well-practiced hands. Another noteworthy

Fig. 14c. Stone rivets on the retaining wall.



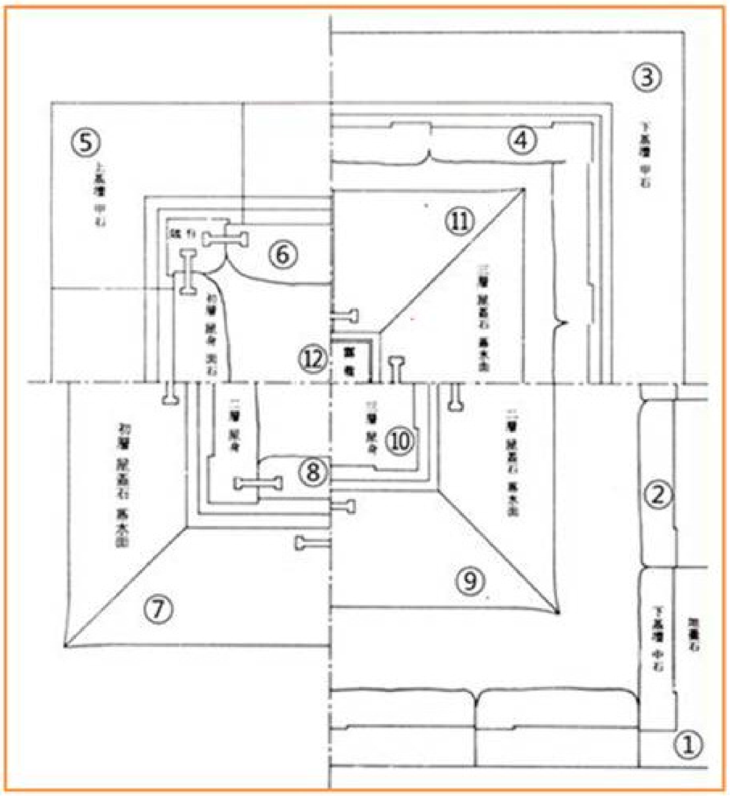
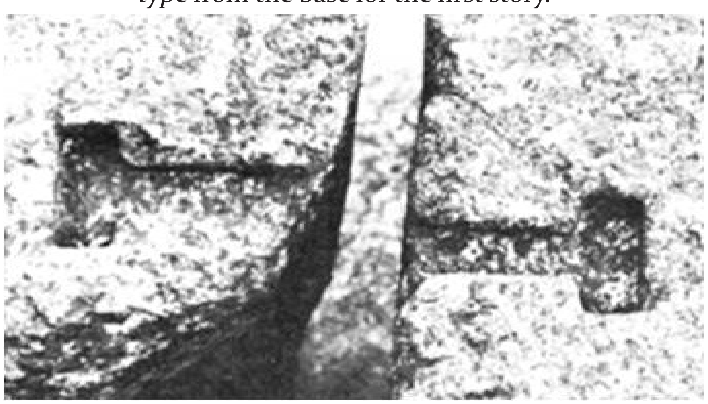


Fig. 15a. Left: Three-story stone pagoda, 682-686, from Koseun-sa temple site, Gyeongju National Museum; Right: Cross-sectional diagram showing location of square-head type clamps.*

structural engineering technique at this site includes the stone riveting applied to the retainment wall along the sloping hill [**Fig. 14c**]. This very technique, a common feature in Roman buildings and bridges and also visible on the Zhaozhou Bridge of China, later evolved for a strikingly creative application at the Seukguram dome discussed below.

The Gameun-sa pagodas seem to have laid the foundations for contemporary and later Silla pagodas in basic structure and in the *eun-jang* technology. The "square-head" type was the prevailing clamp type during the following decades, as confirmed by the following two pagodas in Gyeongju:

Fig. 15b. Right: Five-story stone pagoda (in situ), ca. 700, Nawon-ri, Gyeongju; Below: Clamp groove for square-head type from the base for the first story.



the three-story stone pagoda (10.9 meters in height) from the Goseun-sa temple site 高仙寺址 (now removed to the Gyeongju National Museum) and the five-story stone pagoda (10 meters in height) at the Nawon-ri temple site 羅原里寺址 [**Figs. 15a, 15b**].[33]

Three-Story Stone Pagoda at Bulguk-sa Temple

The Bulguk-sa 佛國寺 ("Realm of Buddha" Temple) in Gyeongju was established under the auspices of the Unified Silla royal house in 751. Nestled at the foot of the sacred Toham mountain 吐含山, it is the best preserved among the Silla temples and famous for its architecture, two stone pagodas, and sculptural icons. During the Japanese invasion from 1592 to 1598, the temple lost all of its wooden components, leaving it with only a stone substructure and stone pagodas. After going through many repair efforts, it was finally restored to its present condition in 1973.[34] Now an active temple, it is inscribed as a UNESCO World Heritage Site together with the related Seokguram 石窟庵 grotto temple. The temple's original construction was carried out during the reign of King Gyeongdeok and supervised by the Prime Minister Kim Daeseong 金大城 (700-774), who was also in charge of the Seokguram project. In the central courtyard stand two stone pagodas, Dabo-tap 多寶塔 ("Prabhutaratna Pagoda") and Seukga-tap 釋伽塔 ("Shakyamuni Pagoda"), which flank the main Buddha hall in front.

The Dabo-tap Pagoda is famous for its unique sculptural masonry with the joinery technique, much like the intricate Lego artistry. As a result, *eun-jang* stone joints were unnecessary at this pagoda. *Eun-jang* clamps are reported only from the Seukga-tap pagoda, which is built of flat-joined stone-blocks. It inherited the same square plan and the general form of the Gameun-sa pagodas, but turned to smaller-volume stones and much simplified masonry.

The Seukga-tap pagoda measures approximately 7 meters in height and 4.4 square meters for the bottommost base (nearly half of the Gameun-sa base). As the result of a simpler approach in its masonry compared to the Gameun-sa pagodas, it replaced cut-stone assemblies by singular monoliths, with the exception of the two-tiered base. This resulted in a reduced number of stone-blocks (down to 27 from the 82 of the Gameun-sa pagoda) and far fewer *eun-jangs* (from 58 down to 10). All 10 *eun-jangs* were installed on the capstones of a two-tiered base, each assembled from four cut-stone blocks [**Fig. 16**].[35] Of significance is the change in the *eun-jang* typology. Here the square-head Gameun-sa type is no longer used; instead, the heads are given the shape of a half-circle. The average length of clamps is 40-54 centimeters. They were cast-iron clamps set into grooves with lead as

Fig. 16. Left: Three-story stone pagoda ("Seokgatap"), ca. 751, Bukguk-sa temple, Gyeongju (arrows point to clamp locations); Right top: Installation condition of clamps on the four stone-block assembly for the cover-stone of the upper-tier base; Right bottom: four extracted iron clamps of half-circle head type.

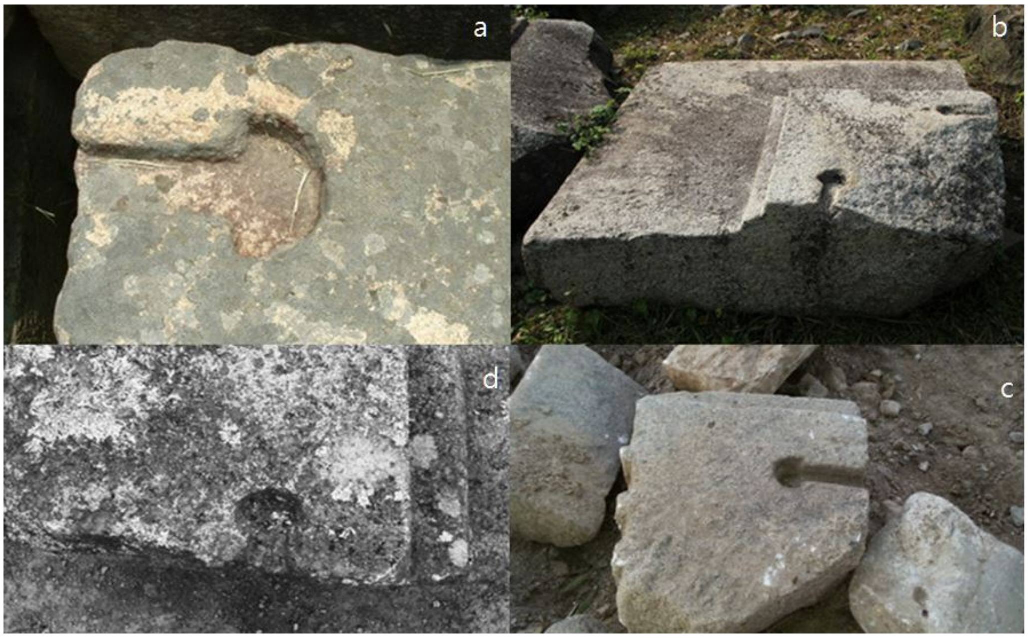


Fig. 17. Examples of half-circle head type clamp grooves from: a) Janghuang-ri temple site, b) Inyong-sa temple site, c) Guhuang-dong temple site; d) Howon-sa temple site. All are datable to latter half of 8th c., Gyeongju.

filler to secure the *eun-jangs* and act as a preservative against rust.

Fully endowed with royal prestige and praised for its innovative masonry and aesthetic excellence, the Seokga-tap became the most influential pagoda in masonry technique, style, and clamping technology soon after its completion. Its half-circle head type *eun-jang* became the standard and found its most refined application in architectural context at the Seokguram, a joint building project with the Bulguk-sa temple. Other evidences for the half-circle type *eun-jang* come from the stone blocks of collapsed pagodas of the mid- to late-8th century at several temple sites. These include the Janghuang-ri temple 獐項里寺址, the Inyongsa temple 仁容寺址, the Guhuang-dong temple 九黃洞寺址, and the Howonsa temple 虎願寺寺址, all located in Gyeongju [**Fig. 17**].[36] It is evident that by the middle of the 8th century the half-circle head type had made the earlier square-head type archaic. Accordingly, this typological switch of *eun-jang* around the middle of the 8th century also offers a useful tool for the periodization of undated or misdated stone monuments that bear *eun-jangs* or *eun-jang* grooves.

As evidence of the best masonry technology of the time, the Bulguk-sa complex also boasts other sophisticated devices for structural reinforcement. They include an imposing retainment wall with uniquely designed stone-rivets and two stone-stairways (which lead up to the central courtyard) with barrel-vault underpasses whose entrance arch is fitted with a wedge-shaped keystone at the apex, in reminiscence of Roman-style keystone arches.

Two Bridges: Woljeong-gyo and Chunyang-gyo

These two bridges were constructed over the Muncheon Stream 蚊川 (also called Nam-cheon 南川), which spans about 61 meters at its widest stretch. The stream separates the Silla palace compound from the southern district of Gyeongju, where the Nam-san 南山, a sacred Buddhist mountain, was frequented by Silla royals. Both bridges, which stand 220 meters apart from each other, were completed in 760 CE in the reign of King Gyeongduk, the monarch who also supported the Bulguksa-Seokuram project. Judging from the last repair record in the year 1280 for the Woljeong-gyo, the bridges most likely remained in use for more than 520 years. Now the restored Woljeong-gyo stands in situ.

Based on material excavated at these sites since 1984, it is clear that the two bridges shared the Chinese style of a "covered bridge" 樓橋 with stone piers, complete with a wooden bridge-deck with stone balustrades supported by multi-layered flying wooden buttresses (built over the piers and the abutments), and a tile-roofed superstructure.[37] The structure of the piers was reinforced by joining stone blocks with e*un-jangs* as indicated by the clamp grooves on the pier stones, while the abutment walls were reinforced by the insertion of stone-rivets, each about one meter in length.

The Woljeong-gyo ("Moon-Purified Bridge") is 61 meters long, 14 meters wide, and supported by four piers separated by 14-meter intervals.[38] The piers consist of stack-up cut-stone blocks with one end streamlined into a "V" shape [**Fig. 18**]. The

Fig. 18. Left top: One of the piers of the Woljeong-gyo Bridge, completed in 760, Gyeongju; Left bottom: Example of a half-circle head type clamp-groove on a pier-stone. Right: Reconstructed Woljeong-gyo at present. Center top: Stone-rivets on the north-side abutment wall; Center bottom: a detail of one stone-rivet.

piers measure 13 meters long and 2.8 meters wide at the bottom-most level. The length of the stone blocks ranges between 128.9-306 centimeters and the width ranges between 54-90 centimeters. Peculiarly, the *eun-jang* grooves show the use of two different types: the old-fashioned square-head type for piers 1, 2, and 3 (from the south) and the prevailing half circle head type for pier number 4.

From the perspective of typological chronology, this situation places into question the date given for the construction of the bridge.[39]

The Chunyang-gyo 春陽橋 ("Bridge of Spring Light") is smaller than the Woljeong-gyo, measuring 55 meters long and 15 meters wide, with one less pier. All three piers are streamlined at both ends with the traces of a *eun-jang* device. But curiously, the *eun-jang* grooves here point to three types: the square-head type on pier number 1, both the square-head and the half-circle head types on number 2, and the most unexpected "dovetail" type on number 3 [**Fig. 19**]. The last one was unprecedented and not to reappear in Korea's *eun-jang* history. Material analysis carried out on the *eun-jangs* collected from underwater debris nearby confirmed they were wrought iron, with an average of 30 centimeters long.[40]

How can we interpret this jarring presence of three types of *eun-jangs*—old, current, and "foreign"—on these bridges? The presence of square-head type clamps may indicate that construction undertaken in the year 760 was in actuality a major reconstruction of the bridges, recycling much of the earlier stone material which bore the square-head *eun-jangs.* In fact, this speculation is backed by archaeologically confirmed traces of earlier bridges at the site. The curious appearance of the dovetail type on one of the piers on the Chunyang-gyo suggests a connection to China, though this is mere speculation. It is clear, however, that it was a prevailing type in contemporary northern China and that it had been gaining greater popularity due to its prominent presence on the famed Zhaozhou Bridge. Not only that, but news of the bridge had reached Korea and Japan by the time the Chunyang-gyo was constructed.

The Seokguram Buddhist Temple

The Seokguram 石窟庵 ("Stone Grotto Her-

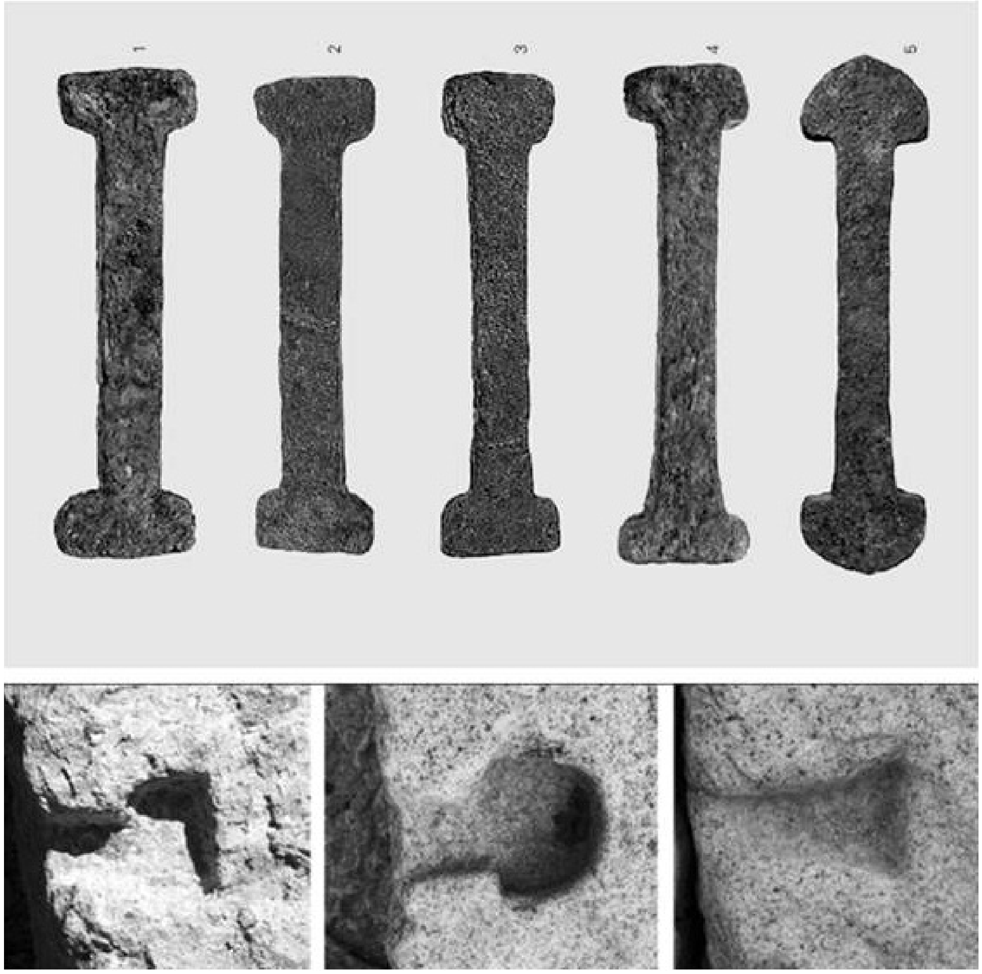


Fig. 19. Top left: Remains of No. 3 pier on Chunyang-gyo Bridge; Bottom left: Clamp-grooves of dovetail-type from No. 3 pier; Top right: Square-head type and half-circle head type iron clamps excavated near No. 3 pier; Bottom right: Three types of clamp-grooves (from left): square-head type, half-circle-head type, and dove-tail type.

mitage") is a Buddhist sanctuary (originally called Seokbul-sa 石佛寺, or "Stone Buddha Temple") nestled on the eastern side of Toham-san, a sacred mountain to the Silla people. It is reachable by climbing up about four kilometers from its head temple, the above-mentioned Bulguk-sa. A UNESCO World Heritage site since 1995, it is renowned in the history of Buddhist art and architecture. Its construction began in c. 742 CE under the supervision of the aforementioned Kim Daeseong, who completed the Bulguk-sa in 751 CE and continued overseeing the Seokguram project until his death in 774, just before its completion. The temple stood pretty much intact, requiring only partial repairs (in 1703, 1758, 1891) until the 20th century, when full restoration works were carried out in 1913-15 (in the Japanese occupation period) and in 1963-64. The Seokguram was officially re-opened on July 1, 1965.[41]

The temple at first glance resembles a tumulus leaning on a mountain slope. Under the grassed earthen mound is a dome architecture consisting entirely of dry ashlar masonry. To enter the temple proper one must go through a reconstructed tile-roofed wooden entrance on a raised platform. Its basic layout includes a rectangular antechamber and then a narrow corridor, all lined up with bas-relief panels of standing guardian figures, which then finally leads into the circular main hall with a dome ceiling. The total length of the interior is 14.8 meters. The rotunda, free of posts and beams, is 8.7 meters in height and 6.5 meters in diameter. It houses the main image of the Buddha seated on a lotus throne, both sculpted in stone and measuring 4.4 meters in total height. The enthroned Buddha was installed prior to the building construction [**Fig. 20a**].

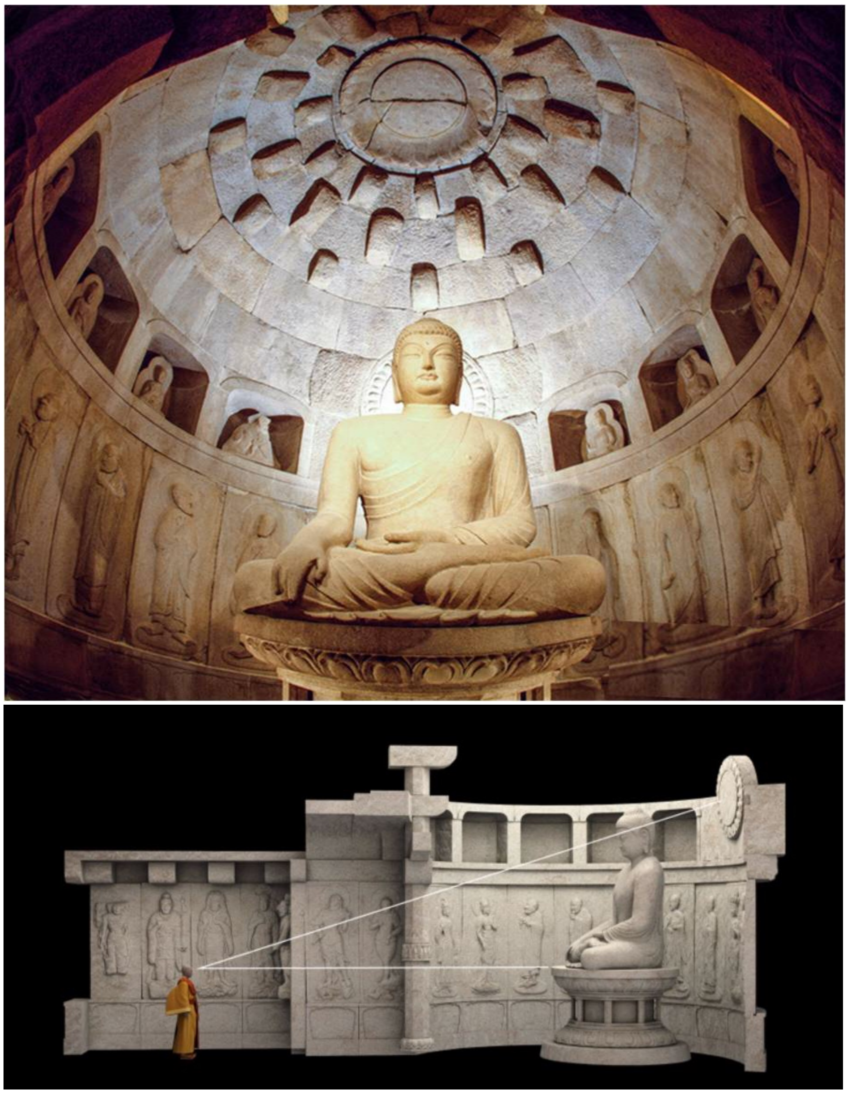


Fig. 20a. Top: Seokuram Grotto Temple, Main Hall, mid-8th c., Gyeongju; Bottom: Three-dimensional view of the left-side interior, from the National Museum of Korea's documentary "Seokguram Grotto, World Heritage Site."

The enthroned Buddha is surrounded by a circular wall, which consists of three components: 15 stone wall panels of auxiliary images, one large stone block containing a lotus flower in relief and aligned with the back of Buddha's head as a nimbus, and a series of 10 niches of seated bodhisattva images installed above the wall and below the dome proper. Between the Buddha and the wall is an interval space allowing circumambulation. Embodied in the design and its execution is a sophisticated knowledge of mathematics, geometry, and dynamics. Each stone member is precision cut in perfect order, ready for assembly in the same vein as the Dabo-tap pagoda of Bulguk-sa.

When the temple was dismantled in 1913-15 for the first time in its history, twenty-six iron *eun-jang* clamps were found on the foundation stones, as well as on the lintel stones. The clamps found on the foundation and the lintel stones are the same as the Seukga-tap type *eun-jangs* with half-circle heads, measuring 30 centimeters in length with its center-bar 3.5 centimeters wide and head 7.5 centimeters wide (based on the clamps from the lintel) [**Fig. 20b**].[42] Not only are they found in a true architectural context for the first time, but also with the precision of stone masonry and casting technique for *eun-jang* installation at the highest order. By this time the *eun-jang* technology had been in practice for more than half a century. Built of only one layer entirely out of cut-stone granite blocks with no mortar, the stability of the foundation and the lintel was of critical importance. The Gyeoungju area is known for seismic activities in both the past—the most devastating one occurred in 1036—and present. Its survival for more than 1,200 years can also be attributed to other measures of structural reinforcement in addition to the *eun-jang* device.

The dome is assembled of five raws of flat-joined, curved cut-stone blocks (approximately 360 of them, with neither arch-rib supports nor adhesives), which successfully recede upward to meet with the pinnacle of the dome, that is, the oculus closed with a monolith (estimated at 20 tons). Noteworthy is the ingenious use of two re-enforcement devices for the dome, which are also engaged in iconographic visualization for this Buddhist realm.

One is the use of 30 stone-rivets in the shape of a tight-fisted forearm that are inserted in between every two curved stones of the top three raws (10 for each raw) with interiorly protruding fists and exteriorly extending arms. These rivets, about one meter long, are designed to fit together with the rest and generate impregnable structural power. The 30 protrusions in the form of a triple-layer of lotus petals and the oculus stone carved as a seed room (gynoecium) together turn into a gigantic lotus flower to sanctify the hall. The other re-enforcement device consists of ten niches of stone statues placed in between the lintel and the dome proper. They form a niche-drum (a device for a domed circular hall used in the West) to distribute the vertical pressure and lateral thrust generated by the dome.

Other hidden surprises include two climate-control devices that are critical for structural safety. The first consists of crescent-shape air holes in the back of all the niches, which were created by having their concave back set beyond the outer edge of lintel stone. These in turn are interconnected with the air-circulating exterior pile of pebble rocks right by the wall. The second climate control device is a natural water passage installed underneath the throne [**Fig. 20c**].

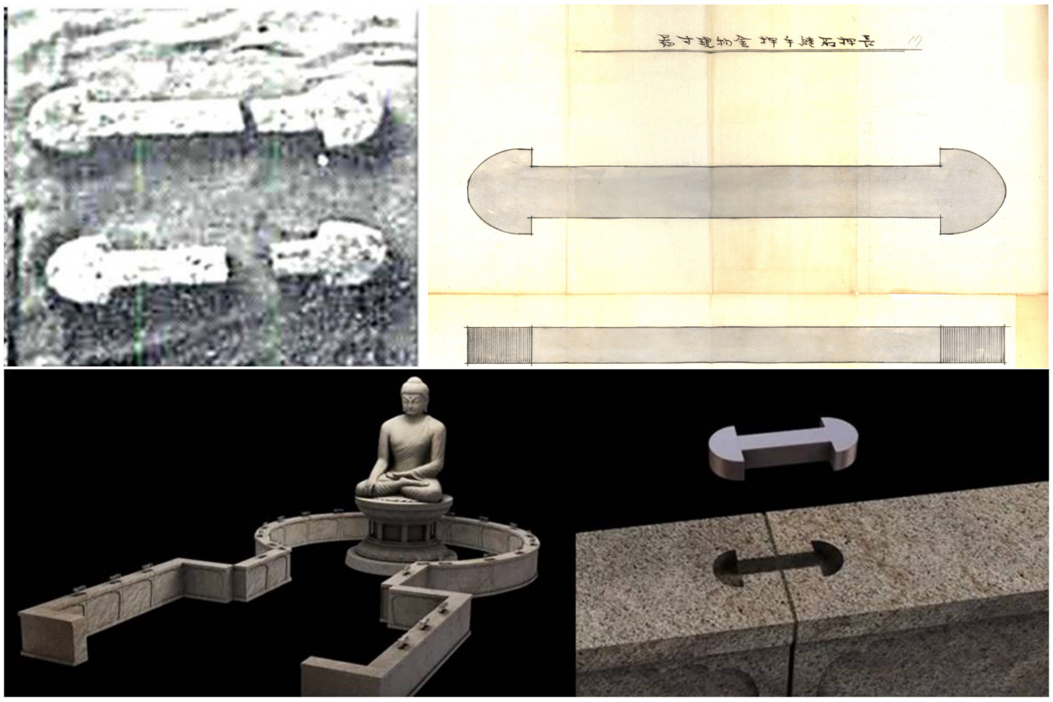
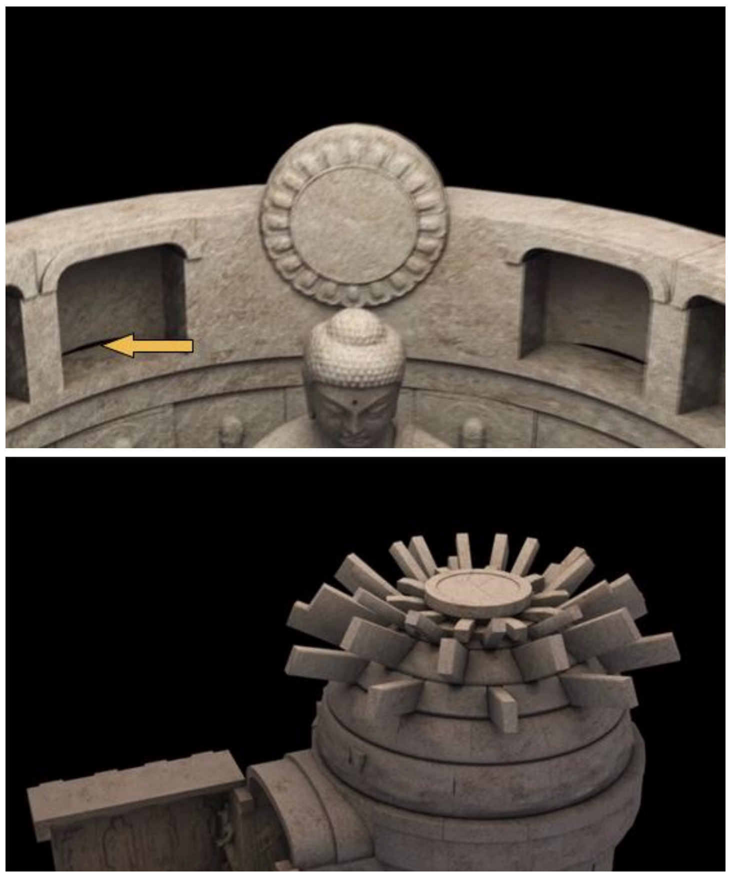


Fig. 20b. Top left: Half-circle head type iron clamps collected during the 1912-1913 Japanese restoration; Top right: Drawing of the clamps found on the lintel stones, from the Japanese report on the 1912-1913 restoration work. Archival collection, National Museum of Korea. Bottom: The layout plan of foundation stones and clamps with a detail of installation, from the National Museum of Korea's documentary "Seokguram Grotto, World Heritage Site."

Fig. 20c. Top: Detail of niche construction. Below: The inner masonry structure of a Seokguram grotto.



With a full-fledged ashlar masonry dome architecture, the Seokguram is very distinct from the stone-brick or clay-brick domes built in wet method in the Near and Far East. It is also very different from the rock-hewn dome structures of cave temples in Afghanistan (e.g., in the Bamiyan Valley) and in China (e.g., in Yungang and Longmen). Deeply steeped in the universal language of sacred architecture and equipped with highly advanced masonry technology, this mid-8th century domed temple in Korea seems to come remarkably close to Byzantine Roman architecture. Why and how this came about at this particular time and space remain to be answered.

Concluding Remarks

The structural reinforcement device of stone-joint clamping, given its close association with ashlar masonry, spread widely as cut-stone architecture was practiced in many parts of the world. In its long history, the dominant players were ancient Egypt, Greece, Achaemenid Persia, and the Roman Empire. Together, they changed the course of world architecture. Over the course of their development, various types of clamps were invented and circulated, all conglomerating and flourishing in the architecture of the Roman Empire, which was the western end of the Silk Road. Therefore, the story of Near Eastern and Far Eastern stone masonry and the accompanying technologies in the first millennium CE cannot be narrated without reference to the eastward transmission of Roman architectural methods. On its route were the vast domains of the Byzantine Empire and the empire of Sassanid Persia, both of which absorbed the Roman-style architectural tradition. Particularly significant was the latter's centrality on the Eurasian crossroads and its geopolitical relationship with the Far East.

An analysis of Chinese clamps, called *yaotie,* yield the following results. China began using iron clamps by the early 6th century CE. They are found predominantly in northern China and are typologically consistent with the "dovetail" type through the Tang period (618-906). In the lower Yangtze region of southern China, iron clamps dated from the early 6th century show the use of the dumbbell type with a square or circular head, which is different in typology from those in the north.

The survey of Korean clamps, called *eun-jang,* shows that the earliest datable devices come from late 7th century Buddhist stone pagodas, which were already at quite a sophisticated stage in production and application. These iron clamps were used throughout the 8th century and are of the flat dumbbell type, first with a square head (or "T" type) and later by the middle of the 8th century with a half-circle head. This latter type is very different from the northern Chinese type but similar to the southern Chinese type.

The clamp types of both countries, though different from each other, belong to the most common category in the global repertory of clamps, with shared features in production and application. But the different choice of certain types in each country seems to imply their diverging paths of transmission involving different tales of movement, contact, and political and religious interaction. The study of stone-joint clamps also requires attention to other accompanying masonry features so as to better understand the clamp technology with regard to origin and development. Space constraints prevent a full discussion on this aspect.

But it can be said that the applications of clamping technology since the time of its earliest datable appearance reflect the developmental process of stone masonry in each country, with continuous inflow of advanced technical impetus from the West. This resulted in an increasing number of skilled masons and blacksmiths, whose technical expertise culminated in the Zhaozhou Bridge of Sui China and the Seokuram of Silla Korea.

Built with the most consummate artistry, the Zhaozhou Bridge, an open spandrel, segmental single-arch bridge with the longest arch span in the world, along with the Seokuram, the only true ashlar dome architecture in the East Asia, represent epochal achievements in the history of Far Eastern stone architecture. It is hoped that this microstudy on the subject of stone-joint clamps, given their inseparability from stone masonry, will bring forth a heretofore seldom studied international dimension implicit in East Asian stone architecture.

ABOUT THE AUTHOR

Hongnam Kim, who holds a Ph.D. in Art History (Chinese art) from Yale University, is Professor Emerita, Ewha Women's University, Seoul. She started her professional career as a research fellow at the Metropolitan Museum of Art and the Smithsonian Institution and taught Asian art history at the University of Maryland. From 1988–91 she was the Curator of the Rockefeller Collection of Asian Art at the Asia Society, New York. In South Korea, she took directorial positions at the Ewha Women's University Museum, National Folk Museum, and National Museum of Korea. She has been on several international museum advisory boards. Her publications include books, articles, exhibition catalogues encompassing the arts of East Asia. Currently she is the Chief Advisor on Museum Affairs for the City of Seoul. For the last twenty years she has been deeply involved in the heritage preservation in Korea heading the National Trust of Korea Heritage Fund. Recognized for her cultural contribution, she was decorated by the French government with the "Legion d'Honneur" and by the Korean government with the "Mugunghwa medal"). E-mail: <hnkim08@gmail.com>.

ENDNOTES

[1] Some speculate that the device was a natural extension from the preexisting technique in carpentry to bind two pieces of wood together, though impossible to verify due to the long perished ancient wooden structures. But a caution is that the flat-joint clamping technique on cut-stone blocks should not be confused with the mortise-and-tenon methods common in carpentry.

[2] Image sources for Fig. 1 are as follows: 1) Upper Anubis shrine at the Temple of Hatshepsut, Egypt, Deir El-Bahari, c. 1450 BCE (Photographed by the author); 2) Theatre at the Acropolis, Greece, 5-4th BCE (https://www.youtube.com/watch?v=hz7ebSkY2_8); 3) Pasagarde, Iran c. 500 BCE (http://www.pbase.com/k_amj/gallery/passargad); 4) Delphi Temple, Greece, 5th-3rd C. BCE (https://www.coastal.edu/intranet/ashes2art/delphi2/misc-essays/masonry.html); 5) Oikio Temple, Turkey, mid-4th c. BCE (http://www.labraunda.org/Labraunda.org/Oikoi_Building_eng.html); 6) Roman Forum, Rome, Mid-1st c. BCE (G. Gorski, *The Roman Forum*, Cambridge University Press, 2015); 7) Pompeii, Italy, datable efore 79 CE (http://kenbunden.net/zemiseilive/travel/ eida/itary08/p02/L/1220.html; 8) Aurelian Walls, Rome, 271–275 CE (https://www.wikiart.org/en/giovanni-battista-piranesi); 9) Artemis Temple, Sardis, Roman Section, 1st-4thc. CE (http://sardisexpedition.org/tr/search?page=109); 10) Tigranakert Roman Ruines, Armenia. 1st C. BCE (https://en.wikipedia.org/wiki/Tigranakert_of_Artsakh); 11) Tunisia (https://www.pinterest.co.uk/pin/565835140660145405/); 12) Axum, Ethiopia, 3rd-5th c. CE (http://solarey.net/ancient-metal-clamp-keystone-cuts-found-axum-ethiopia-south-sahara-africa/); 13) Puma Punku, Bolivia, pre-Inca (https://www.pinterest.co.kr/pin/474989710438529606/; https://www.flickr.com/photos/rotholandus/7572228870/in/photostream/); 14) Tiahuanaco, Bolivia, pre-Inca (http://historyrunamok.blogspot.com/2013/07/tiauanaco-true-ancient-msytery.html); 15) Tiahuanaco, Bolivia, pre-Inca (http://historyrunamok.blogspot.kr/2013/07/ancient-msytery.html); 16) Bijamandal Complex, India, pre-13th c. CE (https://www.indiamike.com/india/madhya-pradesh-f36/trip-report-bhopal-is-not-a-place-to-like-also-sanchi-bhimbetka-bhojpur-1208485/3/#post1759033); 17) My Son, Vietnam, ca. 10th c. CE (https://www.youtube.com/watch?v=Na7qO10GNQY); 18) Ankor Wat, Cambodia, ca. 10th c. CE (https://www.pinterest.co.uk/pin/565835140660145405/); 19) Angkor Wat, Cambodia, ca. 10th c. CE (https://www.youtube.com/watch?v=cCEIUd5w6y8); 20) Borobudur Indonesia. ca. 9th c. CE (https://www.youtube.com/watch?v=Na7qO10GNQY); 21) Imperial Palace, Tokyo, Japan, ca. 17th c. CE (photographed by the author).

[3] Scholarly attentions on the device have been site-specific and sporadic, mostly buried in the archaeological and restoration documents, while amateur scholars' jubilant blogs, though of valuable information sources, tend to mystify the finds as "megalithic anomaly" with little interest in their historicity. See, for example, "Mystery of ancient metal clips," (https://www.kramola.info/vesti/letopisi-proshlogo/zagadka-drevnih-zazhimov-iz-metalla?page=47); and "Amazing metal clamps all over the ancient world" (http://www.revelations-of-the-ancient–world.com/). As for Japan, by present knowledge, stone-joint clamps seem to appear when the era of fortress-castle building began in the 16th century; commonly called "*chikiri*" 契り, they belong to the butterfly type made of bronze, iron, or lead, as discovered at the Nakno-mon (中之門) of the Imperial Palace 皇宮, Tokyo (see fn. 3 above). For more information on the Japanese clamps, see fn. 1 above (Kim 2019a, fn. 4. Pl.1-2).

[4] Peng Minghao 彭明浩, *Yungang Shiku de Yingzao gongcheng* 雲崗石窟的營造工程 [A Study on The Construction Process of the Yungang Grotto], Beijing: Wenwu chubanshe, 2017:225, pls. 5, 10-11.

[5] Luoyang-shi Faxian Yizuo Diling-ji Bei Wei Muzang 洛阳市发现一座帝陵级北魏墓葬 [An imperial mausoleum-level Northern Wei tomb found in Luoyang] (2013-10-25: Luoyang News 洛阳新闻).

[6] Nicola Di Cosmo and Michael Maas, eds., *Empires and Exchanges in Eurasian Late Antiquity: Rome, China, Iran, and the Steppe, ca. 250–750*. Cambridge: Cambridge University Press, 2018: 635-702 (Chapter, "Nomadic Interaction with the Roman and Byzantine West"). Daniel C. Waugh, "Nomads and Settlement, New Perspectives in the Archaeology of Mongolia," *The Silk Road* 8 (2010): 97–124.

[7] Li Yusheng, "Study of Tombs of Hu People in Late 6th Century Northern China," *Newsletter di Archeologia CISA* (Centro Interdipartimentale di Servizi di Archeologia, University of Naples "L'Orientale"), Volume 7, (2016): 91-133. Bonnie Cheng, "The Space Between: Locating 'Culture' in Artistic Exchange," in *Ars Orientalis*, published by The Smithsonian Institution, Vol. 38 (2010): 81-120 (Theorizing Cross-Cultural Interaction among the Ancient and Early Medieval Mediterranean, Near East and Asia). Luo Feng. "Sogdians in Northwest China," in Annette L. Juliano and Judith A. Lerner, ed., *Monks and Merchants: Silk Road Treasures from Northern China, Gansu and Ningxia, 4th-7th Century,* New York (Abrams and The Asia Society), 2001: 239-345. Rong Xinjiang 榮新江 and Luo Feng 羅豐 ed., *Sutejen zai Zhongguo: Kaogufaxian yu chutuwenxian de xinyinzheng* 粟特人在中國: 考古發現與出土文獻的新印證 [The Sogdians in China: New Confirmation of Archaeological Discoveries and Unearthed Documents] (2 vols), Peking: Kexue chubanshe, 2016.

[8] Zheng Linquan 程林泉, et al., *Xi'an beijiao Beizhou Li Dan mu* 西安北郊北周李誕墓 [The Tomb of Li Dan in the northern suburb of Xi'an] in Guojia Wenwuju 國家文物局, *Zhongguo zhongyao kaogu faxian* 2005. [Important archaeological discoveries-2005], Peking: Wenwu chubanshe, 2006: 125 (illustration). *Yiqian wubai nian de shiguan, zangyou guonei shouci faxian qushi de Yinduren, Guangai bei panliang* 一千五百年前的石棺，葬有國內首次發現去世的印度人,棺蓋被盤亮, kknews 每日頭條 (2019-07-07: https://kknews.cc/culture/34mg9m0.html).

[9] Yang Junkai 杨军凯 et al., *Xi'an Bei Zhou Liangzhou Sabao Shi Jun mu fajue jianbao* 西安北周凉州萨保史君墓发掘简报 [Summary Report on the Excavation of the Liangzhou Sabao Shi's Tomb of the Northern Zhou Dynasty in Xi'an], Wenwu 文物, 2005, No. 3, 2005-4-3; Yang Junkai, *Bei Zhou Shi Jun mu* 北周史君墓 [Northern Zhou Tomb of Shi Jun], Peking:

Wenwu chubanshe, 2014. Tomb_of_Wirkak (https://en.wikipedia.org/wiki/Tomb_of_Wirkak). Julie Bellemare and Judith A. Lerner , "The Sogdians Abroad, Life and Death in China," in Freer/Sackler, Smithsonian Institution, The Sogdians Influencers on the Silk Roads project, 2019 (https://sogdians.si.edu/the-sogdians-abroad/; https://sogdians.si.edu/shi-juns-sarcophagus/). Li Yusheng (2016): 99-101.

[10] See fn. 7 above (Li Yusheng, 2016: fig. 17). See fn. 9 above (Yang Junkai, 2014: 60, 59, fig. 54).

[11] The clamps from the drawing resemble the "butterfly-type" 蝴蝶形 (also called "bo-tie" type in the West). But this type became popular after the Tang period. The terms such as "tenon" 榫 and "mortise-tenon" 榫卯 are for timber-joints, but unusual for stone masonry, particularly not applicable to flat-surface stone-joint clamps.

[12] Wu Hung, "A Case of Cultural Interaction: House-shaped Sarcophagi of the Northern Dynasties," *Orientations*, 33, No.5 (2002): 34-41, fig. 13. Zhou Fanwen 周繁文, *Sui-dai Li Jingxun Mu Yanjiu-Jian lun Tang yichuan fangxing shijuangju de shiyong beijing* 隋代李静训墓研究——兼论唐以前房形石葬具的使用背景 [Study of the Sui Period Li Jingxun Tomb: Also on the Background of the Use of House-shaped Sarcophagi before the Tang Dynasty] from *Huaxia Archaeology* (2012-01:www.cnki.com.cn). "9 sui nutong zhi muke you "kaizhe jisi" 9歲女童之墓刻有開者即死 [The tomb of a girl of 9-year has an inscription, "The one who opens (it) will meet immediate death"], kknews 每日頭條 (2017-05-15: https://kknews.cc/culture/k38mvnb.html); https://kknews.cc/story/925ba95.html. For Li's family tree, see *Ningxia Guyuan xijiao xiang shengoucun nan de Bei Zhou Li Xian Mu* 寧夏固原西郊鄉深溝村南的北周李賢墓 [The tomb of Li Xian in the south of Shengou village in the western suburb of Guyuan, Ningxia] (https://kknews.cc/culture/9ovb6z8.html and http://www.sohu.com/a/252131185_100174912). Li Xian (D.569) was her great-grandfather.

[13] Sun Wujun 孫武軍, *Beizhao Sui Tang ruhua Suteren Muzang tuxiang de wenhua yu shenmei yanjiu* 北朝隋唐入華粟特人墓葬圖像的文化與審美研究 [A study on the culture and aesthetics in the iconography expressed on the mortuary furnishings in the tombs of the Sogdians who entered China during the northern dynasties and Sui-Tang period], Northwestern University 西北大學, Ph.D. thesis (2012). He Xilin. "Northern Dynasties Period Stone Coffins and Funerary Couches with Pictorial Carvings" (in Chinese with English summary) in Wu Hung, ed., *Between Han and Tang: Visual and Material Culture in a Transformative Period,* Beijing: Cultural Relics Publishing House, 2003: 341-376. Annette L. Juliano and Judith A. Lerner, "Stone Mortuary Furnishings of Northern China," in Gisele Croes, *Ritual Objects and Early Buddhist Art,* Brussels, 2004: 15-23, pl. 24-57.

[14] I am grateful to Dr. Judith A. Lerner for updating me with valuable information on the couch-type coffins discussed below (by a correspondence of 2020-09-27).

[15] Tianshuishi Bowuguan 天水市博物館, *Tianshui shi Faxian Sui Tang Bingfeng shiguanchuang mu* 天水市發現隋唐屏風石棺牀墓 [A Sui-Tang Period Tomb with a Stone Coffin-bed and a 'Screen' Discovered in Tianshui City], *Kaogu* 考古, No.1 (1992): 46-68, pl. 2-c. The rear view of the Tianshui couch was taken by Luo Feng, Director of the Ningxia Archaeological Institute, Yinchuan and Director of the Guyuan Archaeological Museum (kindly forwarded by Dr. Judith Lerner).

[16] Judith A. Lerner, "Aspects of Assimilation: The Funerary Practices and Furnishings of Central Asians in China," *Sino-Platonic Papers*, 168 (2005): pl. 6a. "Drawing of the bed reconstructed." (sourced from Musée Guimet. *Lit de pierre, sommeil barbare. Présentation après restauration et remontage,d'une banquette funéraire ayant appartenu à un aristocrate d'Asie centrale venu s'établir en Chine au VIe siècle*), Paris: Musée Guimet, 13 (2004). See also Rong Xinjiang 榮新江, et al. *Sutejen zai Zhongguo: Lishe, Kaogu, yuyan de xin tansuo* 粟特人在中國: 歷史, 考古, 語言的 新探索 [The Sogdians in China: New Investigation into History, Archaeology, Language], *Faguo Hanxue* 法國漢學, Series no. 10, Peking: Zhonghua Shuju, 2005: pl. 5. The Kooros bed is now back to the owner in Texas, USA. The same type of funerary couch in the Miho Museum, Japan most likely had the same dovetail clamps based on its structure and style, although the panels are currently joined by braided wire threaded through iron rings that were set into the sides of the panels (according to Dr. Judith Lerner).

[17] Li Hejun 李合群, *Xiancun zuigulao de shigongqiao* 現存最古老的石拱橋 [The oldest surviving stone arch bridge], *Zhongguo gudai qiaoliang wenxian jingxuan* 中國古代橋梁文獻精選 [Selected Literature on the Ancient Chinese Bridges], Wuhan: Huazhong Keji Daxue chubanshe, 2008. A good introduction and images for the bridge are found in Zaozhou qiao 趙州橋 (2019-03-19: https://zh.wikipedia.org/wiki/趙州橋); Best China News (http://www.bestchinanews.com/History/1979.html). This part of Hebei province was known for rich mineral deposits and quarries (identified as the source of material for the Zaozhou Bridge) as well as the community of skilled stone masons and craftsman, as suggested by the place name, "Shijiazhuang" 石家庄 (literally meaning "Stonemason's Lodge").

[18] Liang Sicheng 梁思成, "Xianhua wenwu jianzhu de zhongxiu yu weihu" 閑話文物建築的重修與維護 [A discourse on the restoration and protection of heritage architecture], *Wenwu* 文物, No. 7 (1963). In the restoration process, about one third of the original stone material was replaced with new materials, using mortar cement, while some clamps were also removed (probably from the deck and the underside of the bridge), despite the opposition and criticism from Liang and other scholars. Resultantly, the clamps, reduced in number, at present no longer perform structural-reinforcing function.

[19] Zhang Jiazhen 張嘉貞 (666-729), *Shiqiao ming bingshu* 石橋銘幷書 [Encomium on the Stone Bridge with a Preface], composed ca. 720s in *Hantian* 寒天 ed. *Quan Tangwen* 全唐文 [Collectanea of Tang dynasty Literature], Tanbian: Yanbian daxue chubanshe, 2003: 127-139. Zhang twice served as prime-minister 中書令 at the Tang court. The Sui-dynasty date given by him has been unquestioned owing to Zhang's status as a scholar-official and the proximity of his years to

the time of the bridge construction. But the exact construction years are unknown; many different dates have been suggested with no supportive evidence. In my opinion, since the bridge, masterful and aristocratic in every sense, could not have been an ordinary bridge for local pedestrians, it would be better to investigate the years when the imperial army or family (including the emperors) passed through the area or its possible connection with the renowned Bolin monastery 柏林寺 in the neighborhood.

[20] As far as is known, the ancient Romans were the first to develop the segmental arch and the open-spandrel segmental arch bridge, such as the Pons Fabricius in Rome, which was completed in 62 BCE (now the spandrel sections are lost). See Ian Dahl, "Pons Fabricius: Rome's Timeless Bridge" (2017-09-15: https://brewminate.com/pons-fabricius-romes-timeless-bridge/). For detailed drawings and information on the ancient Roman monuments, architecture, and bridges, see the collection of etching works (total 1,355 etchings) by Giovanni Battista Piranesi (1720-1778) in his *Le antichità Romane* [The Roman Antiquities] *in WIKIART Visual Art Encyclopedia* (https://www.wikiart.org/en/giovanni-battista-piranesi). As for Persia, a good example is the dam/bridge "Pol-e Kaisar" [Caesar's bridge] in Shushta, built in the mid-3rd century CE, which was among many Roman constructions done by the Roman soldiers taken as captives from the battle of the victorious imperial armies of Šāpūr I (r. 241~272 CE) of Persia against the Roman army of Valerianus (r. 253~260 CE). Pol-e Kaisar (https://en.wikipedia.org/wiki/Band-e_Kaisar). Roman troops had military engineers (to build roads, camps, fortified walls, bridges, etc.) and soldiers were trained in all fields to be self-sufficient. The Roman and Persian examples given here had stone-joint clamps.

[21] The Yongtong Bridge (3,200 cm long, 634 cm wide) closely follows the Zhaozhou Bridge in style and masonry; the identical dovetail clamps (64 in total) are visible on its main arch (https://baike.baidu.com/item/永通橋/13206503?fr=aladdin). The bridge at the Xuankongsi (also known as Fuqing Si) is also a spandrel-arch bridge (15-meter span) crossing over a narrow gorge (52 meters deep) on which the Qiaolou Dian 桥楼殿 (Bridge-Tower Hall) stands. Despite its poor condition with patch repair works, its genuine indebtedness to the Zhaozhou Bridge is apparent in many features (making its traditional Sui dating not too far off), including the overall proportion of its segmental arch and two arched spandrels, with the same dovetail iron clamps installed in the same manner along the span of arch. The traditional Song (960-1279) date for the Yongtong Bridge is questionable since the dovetail type *yaotie* was no longer in fashion during the Song, having been replaced by the "butterfly" type. The Xuankongsi bridge shares the Lu Ban 魯班 legend with the Zhaozhou Bridge: Lu Ban, the patron deity of builders, is said to have built the Zhaozhou Bridge overnight, while his jealous sister flew over to Mt. Cangyan to build her own bridge (https://baike.baidu.com/item/蒼岩山懸空寺). Other Hebei bridges in the Zhaozhou Bridge tradition date from the Yuan and Ming period; such as Leshan qiao 樂善橋 and Dulin qiao 杜林橋 of Cangzhou 滄州, Hongji qiao 弘濟橋 of Handan si 邯鄲市, all can be checked from Baidu 百科 (baike.baidu.com) and Tang Huancheng 唐寰澄, *Zhongguo Kexue jishushi. Qiaoliang juan* 中國科學技術史・橋樑卷 [History of Chinese Science and Technology. Volume on Bridges], Peking: Kexue Chubanshe, 2000 (2nd Edition).

[22] Originally on the surface of the colosseum's outermost walls were iron clamps amounting 200-300 tons in total weight. See Lynne C. Lancaster , *Concrete Vaulted Construction in Imperial Rome: Innovation in Context*, Cambridge University Press, 2005: Ch. 6 (Metal Clamps and Bars), pp. 113-140. Other examples are the Temple of Augustus on the Philae Island, Egypt (https://www.britannica.com/place/Philae-island-Egypt) and some mausoleums by the Via Appia (see fn. 20. Piranesi, *Le antichità Romane).* For the Mihr-Narseh, see https://en.wikipedia.org/wiki/Mihr_Narseh.

[23] For Li Chun, see Tangyao Wenhua jiangtang*, Yaoshan Shijiang Li Chun yu Zaozhou qiao* 唐堯文化講堂——堯山石匠李春與趙州橋 [Tangyao Lecture Hall - Stonemason Li Chun from Yaoshan and the Zaozhou Bridge], *Longyao fabu* 隆堯發布 2018-10-23 (https://read01.com/xDaxGox.html#.X3XdqMIzaJB). *Quan Pangwei Xiexi Zhaozhou-qiao Geli 1,400-nian de Bimi* 全方位解析趙州橋屹立1400年的秘密 [A comprehensive interpretation of a 1,400-year old secret behind the rise of Zhaozhou Bridge] (https://kknews.cc/news/5b4byq3.html).

[24] Wang Shusheng, "Yuwen Kai: An Epoch-making Oriental Architectural Master," *Journal of Urban and Regional Planning*, New York: Science Publishing Group, 2013-01. Yuwen Kai masterminded the capital city planning and all palatial projects. It is known he took nine months to design a vast capital city at Daxing, six times the size of present-day Xi'an. This Daxing palace had a rotating pavilion accommodating 200 guests. Curiously, only "floating bridges" 舟橋 ("linked-boat bride") are mentioned under his name.

[25] Nanjing Museum 南京博物館 (Xu Huping 徐湖平 ed.), *Nanzhao lingmu diaoke yishu* 南朝陵墓彫刻藝術 [Carved Stone Art in Southern Dynasty Tombs], *Wenwu chubanshe*, 2006: 78. Also see Luo Zongzhen 羅宗眞, *Wei Jin Nanbeichao Wenhua* 魏晉南北朝文化 [*The Culture of Wei-Jin and Southern-Northern Dynasties*]*,* Shanghai: Xuelin Chubanshe, 2000: 57. Luo identifies the clamps on the stone blocks as being of a "T" shape, although to the author some appear to have circular or semicircular heads. My gratitude to Dr. So Hyunsook 蘇鉉淑 (a renowned Korean scholar of pre-Tang Chinese Buddhist art) for the information and photos (from 2020-02) for this Danyang site.

[26] I am informed by Dr. So Hyunsook that the original bridge is given the date of the Southern Dynasties by Professor He Yunao 賀云翱 of Nanjing University, a historian specializing in the Southern-Northern Dynasties period. Dr. So also kindly offered the photos of the piers she took in situ.

[27] Korea had a long history of stone architecture and monuments starting from the prehistoric time of megalithic dolmen to the Three Kingdoms period when dry ashlar masonry was practiced for tombs, walls, foundations for various monuments, small bridges, ice storage, observatory, pagodas, etc. Only two stone pagodas in the old Baekjae territory left some traces of a clamp device, but these are assumed to be post-Baekjae restorations. See fn. 30 below.

[28] The history of the temple is narrated in Iryeon 一然, *Samguk yusa* 三國遺事 [*Memorabilia of the Three Kingdoms*] written by the Buddhist monk Iryeon (1206–1289) in 1281. *Samguk Yusa: Legends and History of the Three Kingdoms of Ancient Korea*, trans. by Tae-Hung Ha and Grafton Mintz, Silk Pagoda, 2006. See also panoramic views of the site presented by the Gyeongju National Museum (https://artsandculture.google. com/exhibit/gameunsa-temple-site/QwKSszaEbQBMIQ).

[29] Kungnip Munhuajae Yeonguso 國立文化財研究所 (National Research Institute of Cultural Property Research), *Gyeongsangbuk-do ui Seoktap* I [Stone pagodas in the Gyeongsangbuk-do Province], *Seokjo Geonchuk Yeongu Jaryo* [Research material for stone architecture], No. 5 (2007): 78, see table "Number of stones used per component for the stone pagoda."

[30] However, the western pagoda of Mireoksa temple 彌勒寺 (in Iksan 益山) did yield several joint-clamps in unusual type applied in haphazard manner, most likely as the result of late reinforcement in the process of modern Japanese restoration. The eastern pagoda left only some stone blocks, one of which has a set of *eun-jang* grooves in the shape of a dumbbell with square head. It is assumed to be from an early Unified Silla restoration because its twin pagoda on the west did not yield such clamps, the debris excavated in situ can be dated to both Baekje and Unified Silla period, the type of clamp is the same as the Gameunsa type, and because the five-storied Jeongrimsa pagoda 定林寺五層塔 (in Buyeo 夫餘), built soon after the Miruksa pagodas in mid-7th century, had no clamps applied.

[31] Kungnip Munhuajae Yeonguso 國立文化財研究所, *Gyeongju Gameunsa-ji Seo-Samcheung Seoktap Suribogoseo* [Report on the restoration of the Western Three-story Stone Pagoda at the Gameun-sa site, Gyeongju], 2010: 76, 142-154; *Gyeongsangbuk-do ui Seoktap* I [Stone stupa of Gyeongsangbuk-do province], 2007: 77; *Gameunsa-ji Dong-Samcheung Seoktap Bosu-jeongbi Bogoseo* [Report on the repair and maintenance work of the Eastern Three-story Stone Pagoda at the Gameun-sa temple site], 2011: 42.

[32] Kungnip Munhuajae Yeonguso, 2010: 142-154, 211-223 and 2007: 77

[33] Kungnip Munhuajae Gualiguk Gyeongju Sajeok Guali Samuso 國立文化財管理局慶州事蹟管理事務所 (Management Office of Cultural Property in Gyeongju), *Goseon-sa-ji Balgul-josa Bogoseo* [Report on the Excavation of Goseon-sa Temple Site], 1977. Geonchuk Munhwajae Yeongusil (Office for Architectural Property Reseach), *Hanguk ui Gogeonchuk* [Old Korean Architecture], no. 7 (1985): 1-19, *Wolseong Nawon-ri Ocheung Seoktap* [Five-story Stome Pagoda in Nawon-ri, Wolseong], p. 14 (for illustration).

[34] Kungnip Munhuajae Yeonguso, *Gyeongju Bulguksa Samcheung Seoktap Suri Bogoseo* [Report on the Restoration of Three-story Pagoda at Bulguksa, Gyeongju], 2017: 9 (fn. 5), 285, 295 (fn. 8), p. 307 and pl. 4 (figs. 82-134); *Kyeongsangbuk-do ui Seoktap* [Stone Pagodas in Gyeongsang-buk Province], 2007: 236-265.

[35] Normally four *eun-jangs* would have been used for an assembly of four cut-stones. The additional two here are applied on the cracked stone blocks; the accident most likely occurred during the original construction, since the extra two clamps are the same as the rest in type, material, and rust condition; the cracked stones were probably kept with additional *eun-jangs* owing to their weight burden and the invisible location of cracks and *eun-jangs.*

[36] a) *Gyeongju Janghwang-ri saji* [The Janghwang-ri Temple Site], (2006.3.22: http://blog.daum.net/kelim/7843495); b) Kungnip Gyeongju Munhuajae Yeonguso, *Jeon Inyongsa-ji Balguljosa Junggan-Bogoseo* [An Interim Report on the Excavation Survey of the Alleged Inyong-sa Temple Site], 2009: figs. 24-26; 76 (Photos 34-37); c) Kim Jihyun, *Gyeongju Guhwang-dong Tapji ui Seoktap Jegochal: Yihyeong-Seoktapseol ae daehan Jeronul Jungsim uro* [Study on the stone material of Guhwang-dong pagoda site: Focused on the review of the hetero-style theory], *Bulgyo Misulsahak* [History of Buddhist Art] 20 (2015.10): 21; d) *Howonsa-ji neun balgul tooneun jeongbi junbi jung?* [Is the Howon-sa temple site in preparation for excavation or repairs?] (2018.09.13: https://blog.naver.com/jw1405/221358251376).

[37] Gyeongju-si 慶州市, *Woljeong-gyo-ji Balgul-Josa mit Bokwon-seolgae Bogoseo* 月精橋址發鋼調查——復元設計報告書 [Report on the Excavation Survey of Woljeong-gyo Site and Restoration Planning], 1986. Kungnip Gyeongju Munhuajae Yeonguso 國立慶州文化財研究所 (National Research Institute for Gyeongju Cultural Property), *Chunyang-gyo-ji (Iljeong-gyo-ji, Sajeok 457-ho) Balgul-josa Bogoseo* 春陽橋址(日精橋址, 史蹟457號)發掘調查報告書 [Report on the excavation and survey of Chunyang-gyo bridge "Iljeong-gyo site, Historical Property No. 457" Report], 2005: 376.

[38] Seo Byoung-Guk 徐秉局, *Chunyang-gyo wa Woljeong-gyo ui chukjo sigi e daehan geumto* 春陽橋月精橋築造時期檢討 [Investigation on the construction-time of Chunyang-gyo and Woljeong-gyo Bridges]. *Jungang Gogo Yeongu* 中央考古研究 [Journal of Central Institute of Cultural Heritage], No. 1 (2005): 253, 245-283.

[39] The *Samguk Sagi* 三國史記 (see fn. 28 above) records two major repairs, one in 798 when damaged by fire and another one in 1280. See fn. 39 (Seo Byoung-Guk, 2005: 251-254). By the time of the first repair, the dovetail type clamps could have been inspired by the Zhaozhou bridge, the type-site of dovetail clamps in China. The Zhaozhou bridge had been known in Korea and Japan before the end of 8th century, along with the nearby historical Buddhist temple, Bolin Chansi 柏林禪寺, which is famous for its connection to the Buddhist monk Xuanzang 玄奘 and its propagation of the "zen" tea ceremony.

[40] An analysis reveals they were produced in a reduction process at low temperature (800-900 degrees Celsius), probably from an outdoor smelting-furnace. See Park Jangsik and Cheung Youngdong, *Gyeongju Iljeong-gyo-ji chulto cheoljae eun-jang ui keumsokhak jeok misae-jojik bunseok* [Metallurgical analysis of microstructure of the iron *eun-jangs* excavated from the Iljeong-gyo bridge site, Gyeongju], in *Kungnip Gyeongju Munhuajae Yeonguso* (2005): 406-410. Iron bars and weaponry had become major export items of the southern Korean peninsula to Japan by the 5th century.

[41] Mungyo-bu 文教部 (Ministry of Culture and Education),

Seokguram Seokgul ui Hyonhwang gwa Bosudaechaek(an)-Bogoseo [Report on the Present Status of Seokguram Grotto and Repair Planning], 1961; *Seokguram Surigongsa Bogoseo* 石窟庵修理工事報告書, [Report on the Repair Work of Seokguram], 1967: 9-15 ("Chronology of Repairs and Rstorations"); *Seokguram Bojon-youngu Jaryo* 石窟庵保存研究資料 [Research Material for Seokuram Conservation], 1970. Munhwajae Gwanri-guk Munhwajae Younguso (Management Office of Cultural Heritage-Center for Cultural Heritage Research), *Seoguram ui Gwahakjeok Bojon ul wihan Jeonmunga Hweuirok* [Minutes from the Meetings of Experts for the Scientific Preservation of Seokguram], 1991. Lee Kang Kun 李康根, *Toham-san Seokgul e daehan Geunchuksa jeok Haeseok* [Architectural Interpretation on the Toham-san Stone Grotto], *Gangjwa Misulsa* 講座美術史 (The Art History Journal), no. 46 (2016.6). National Museum of Korea, 3-D Documentary production (2013) on Seokuram (in English) (https://www.youtube.com/watch?v=HeHy3Ml3818). Seokuram, Seokuram English website (2018: http://eng.seokguram.org/).

[42] Joseon Chongdok-bu 朝鮮總督府 (Colonial Government of Joseon), *Daisho Sam-nyeon-1914 Habangi Seokguram Bojon-gongsa Gwanryeon Munseo* [Document on the Preservation Work of the Seokguram in the latter half of the third year of Daisho Reign (大正3년)-1914], archival collection of National Museum of Korea. This document, hand-prepared by the Japanese restoration team, provides drawings of *eun-jang* from the lintel (named here as *jang'apseok* 長押石, meaning lintel). This is in agreement with the eyewitness account by Kim Sanggi, Mungyo-bu (1961): 79-123. Kim provides the measurement for the lintel clamps but without any accompanying photos. This was the last time the lintel *eun-jangs* were mentioned. The original iron *eun-jangs* were replaced by lead *eun-jangs* during the 1913-1915 restoration and then to titanium *eun-jangs* during the last restoration (1963-1964).