Civil engineering in the unearthing and preserving of historic ruins

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Renovation of stone walls at Sendai Castle

Photo 1 Stone castle walls under renovation

There is an ineffable peace of mind to be experienced standing below the moss and ivy covered stone walls that form the base of a Japanese castle. It derives, I think, from the feeling of proximity to hundreds of years of human history. Yet there is growing concern that traditional techniques of stone-wall building are being lost. This report describes the use of such traditional construction methods in the renovation of stone walls at Sendai Castle, which is now in progress. (Photo 1)

◆ Renovation of stone castle walls

Sendai is at the forefront of development in the Tohoku region, and is one of northern Japan's key cities. A city planning project for the improvement of Aobayama Park has received approval, and work commenced in 1997. The aim of the project is to improve facilities around the ruins of the old castle, which now symbolizes the city of Sendai that developed around it. The castle commands fine views over the city itself, which is often known as the "forest capital," and the park is to be constructed in harmony with the famed history, culture, and natural setting of the city. As the first phase of the project, work to renovate the castle's stone base has been in progress since March, 1998.

◆ History of the castle

The original fortification on the site was known as *Hirayama-shiro* type Castle (castle built on hill and plain). This was built soon after the battle of Sekigahara in 1600 by Date Masamune, the first feudal lord of the Sendai domain, who was known by the name Dokuganryu or "One-Eyed Dragon." The main com-

pound was situated on a natural stronghold rising 131.6 m above its surroundings and protected by a 64 m precipice dropping to the Hirose River to the east and the 80 m deep Tatsunokuchi valley to the south. Further, three large, deep moats and mounds were built on the ridge extending westward from the castle and 20 m stone walls protect the gently sloping north side. Together, these fortifications made the castle an impregnable fortress. Over time, the various structures of the castle have suffered from earthquakes and fire, and were burnt to the ground during World War II air raids.

Currently, the area around the ruins of the castle is known as Aobayama Park — an area of natural beauty and greenery close to the center of the city — and only the stone base of the castle on the north side of the main compound offer a reminder of the past.

◆ Present state of stone walls

The remaining stone walls on the north side have, since around 1960, been noticeably bulging outward and loosening as a result of earthquakes, traffic-induced vibrations from Aoba-jo Road, which runs along the walls, thick vegetation growth, and general aging. In some places, bulging had reached as much as 0.8 m. (Fig. 1)

Under these circumstance, the city took emergency safety measures such as installing displacement meters and introducing road closures when sudden deformations are detected. Rockfall protection fences were put in place at the foot of the walls as insurance against collapse. Further, the city arranged a plan for renovating the walls and worked toward implementing it.

◆ Characteristics of the walls and the renovation project

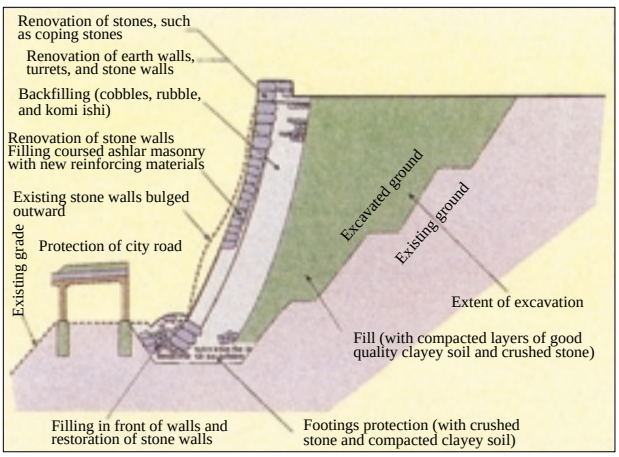
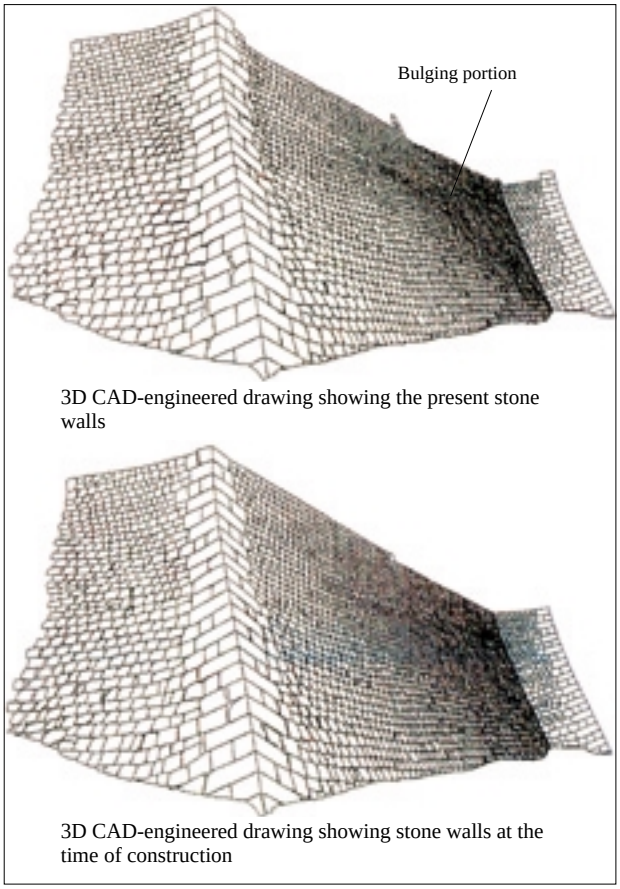


Fig. 1 Section through stone wall



3D CAD-engineered drawing showing the present stone walls

3D CAD-engineered drawing showing stone walls at the time of construction

Fig. 2 3D CAD-engineered drawings

The wall repairs are being carried out with andesitic basalt. A total of about 10,000 stones make up the walls, for a total surface area of 3,380 m^2 and a length of 190 m. The walls are of so-called Kirikomihagi construction, a sophisticated coursed ashlar masonry in which precisely scabbled stones are laid at a steep pitch and without gaps such that horizontal joints are straight. Though such masonry can be seen in the fortified base of the main building of Edo Castle in Tokyo, there is no remaining example as extensive as these remaining walls of the north side of Sendai Castle's main enclosure.

The renovation work on the walls is being undertaken with a view to improving their resistance to disaster while also returning them to their original state without compromising their cultural significance. Part of the rationale behind the work is to hand down the traditional construction skills from generation to generation. To this end, all stones are being removed once from the walls to allow the hidden rear structure to be repaired, and they are then replaced using the traditional construction method. In addition, to clarify the structure of the walls and also shed light on stone wall building techniques that will be needed when the stones are replaced,

removal of the stones is accompanied by a careful excavation survey.

◆ Preparation of three-dimensional CAD drawings for use in restoration

To ensure that the walls could be returned to exactly their original state, it was first necessary to elucidate their original configuration at the time they were constructed. Since no design drawings that could assist in making conjectures about this original configuration exist, a technique for inferring it from the present walls was devised, and from this information design drawings were prepared using a three-dimensional CAD system.

This technique entails first taking photos of the walls, then measuring the dimensions and orientation of each stone (Photo 2) before rendering 3D images based on the data. Taking clues from undeformed stones, the positions of deformed stones at the time of construction are inferred from the results of numerical analysis. Finally, an overall configuration of the walls is developed and design drawings prepared. (Fig. 2)

◆ Removal of the walls and discovery of unusual stone formation

Stones are currently in the process of being removed (Photo 3), while a survey of the sectional structure behind the stones and the foundation ground at the base of the walls is being carried out. The stones are of wedge shape, with one 45-90 cm rectangular face tapering down over a depth of about 1.3 m to a smaller face, and they weigh 0.5-0.6 tons each. Every stone is given an identification number before removal and placed into temporary storage after removal.

During the survey and removal work, rows of stones parallel to the walls were discovered behind the backfill layer. (Fig. 3) The structure of the walls is such that the space between the main stones being removed and the rows of stones is backfilled with cobbles.

It is conjectured, from the evidence of the construction method, that the present walls were constructed in the late Edo period, and the unearthed rows of stones are the remains of walls built during the reigns of the feudal lords Date Masamune and his son, Date Tadamune. It appears that new stones were laid in rows outside older ones as stone wall building techniques became ever more sophisticated.

The rows of stones are now under investigation in the hope of elucidating both the design and construction

Photo 2 Measuring dimensions of stones

Photo 3 Stones being removed

techniques of the time through reference to similar instances at other castles, and also through circular arc analysis. It is considered quite likely that these stones — they may represent part of a wall that collapsed in an earthquake — remain as evidence of a systematic rebuilding technique in which they shored up the later stones to improve workability. Their placement in rows may have been designed to help ensure the stability of the later walls built outside them.

There has been an increasing incidence of such rows of stones being found behind stone walls during restoration work, as at Kanazawa Castle for instance. But never before has the technique been seen on such a large scale.

We have high hopes that this removal and investigation of Sendai Castle walls will shed light on the history of stone wall building and Japan's sophisticated tradition of civil engineering technology.

◆ Difficulties in reconstructing the walls

Once the removal work is complete, the stones will have to be set back in place. The plan is to make full use not only of the original stones but also of the backfilling cobbles and fill. The walls of this type of castle founda-

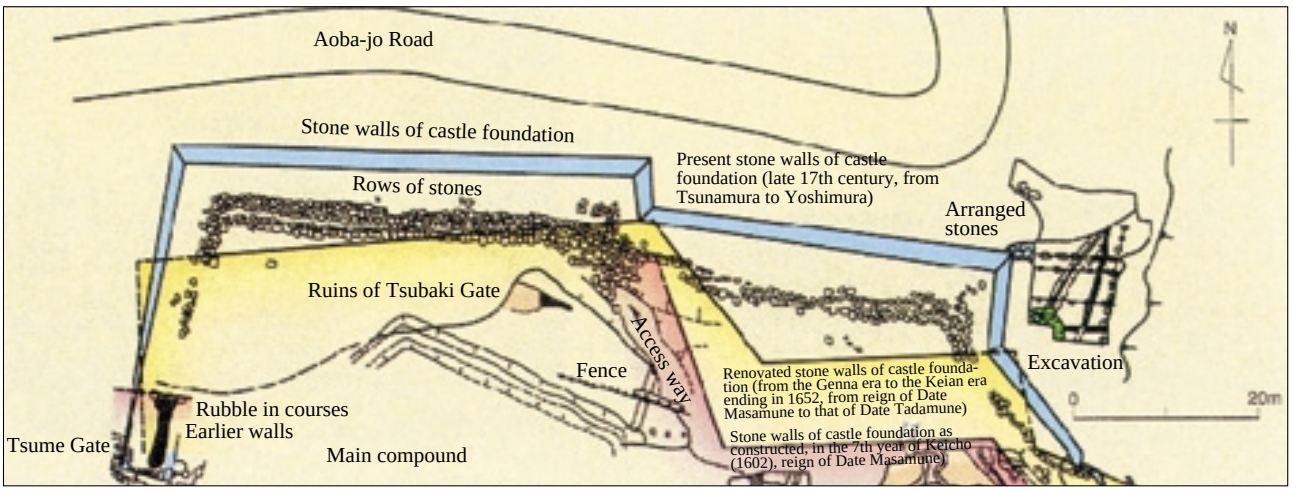


Fig. 3 Plan of stone foundation walls and uncovered rows of stones

tion are concave to keep the enemy out, and they are said to be extremely difficult to restore once dismantled. Even a single misaligned stone can lead to the entire wall being badly out of shape, resulting in failure to return the wall to its original shape. To avoid this, the location and orientation of every stone will be checked and adjusted individually by hand so as to match the design drawings.

◆ Results of the rehabilitation work

Mankind's use of stone dates back to very early times. Beginning with simple stone tools and moving up to large-scale structures, human beings have used stone for most purposes in everyday life. Above all, stone masonry developed fairly early on in human history, and stone has been a mainstay of the development of civilization. In addition to its pure utility value, stone is a material that also has a great potential cultural value.

In other words, the renovation and restoration of stone structures has great significance not in the sense of improving the infrastructure but because it leaves something important for posterity. Of course, the techniques used for renovation and restoration are also important cultural assets.

There are many stone castle walls of great cultural value throughout Japan. Some, like those at Sendai Castle, are in danger of collapse as a result of aging. Under these circumstances, the ongoing project to renovate the walls of Sendai Castle is an important work in which the walls are treated as infrastructure as well as part of our cultural heritage. In a sense it acts as a bridge between the civil engineering technology of the past and future. The project is slated for completion in 2001.

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