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Friction Damper for Seismic Retrofitting on Existing Road Bridges

SUBTITLE: Dice & Rod Type Friction Damper (DRF-DP)

1. Background of Technology Development

It has recently been required that road bridges keep functioning immediately following a great earthquake. Measures have been taken since the Kobe Earthquake of 1995 to prevent road bridges from falling or collapsing as a minimum requirement for seismic retrofit. Despite the bridge being free from collapsing, if the bases of the road bridge are damaged severely, restoring traffic functions requires much time. Therefore, studies are being made on seismic retrofit methods that improve performances using dampers. Most of the methods, however, involve seismic retrofit in the longitudinal direction (in parallel to the main girder). Not many seismic retrofit dampers have been installed in the transverse direction (at right angles to the main girder) because there is limited space and fixed bearings are frequently required against small to medium earthquakes. Thus, we developed a method for seismically retrofitting existing road bridges using the “Dice & Rod Type Friction Damper (DRF-DP)” (Fig.1).

2. Detailed Description of the Technology

DRF-DP is a damper which utilizes friction between metal parts called a die and a rod. They are already being used for the seismic reinforcement of building structures. They are not displaced under the designated load. If the designated load is reached, they

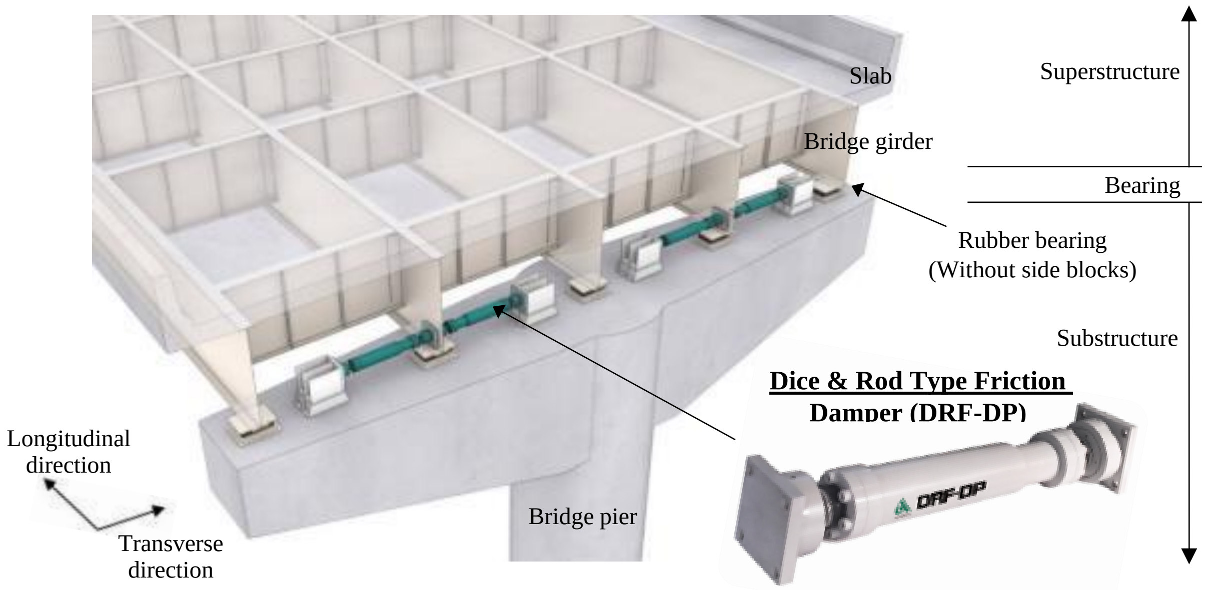
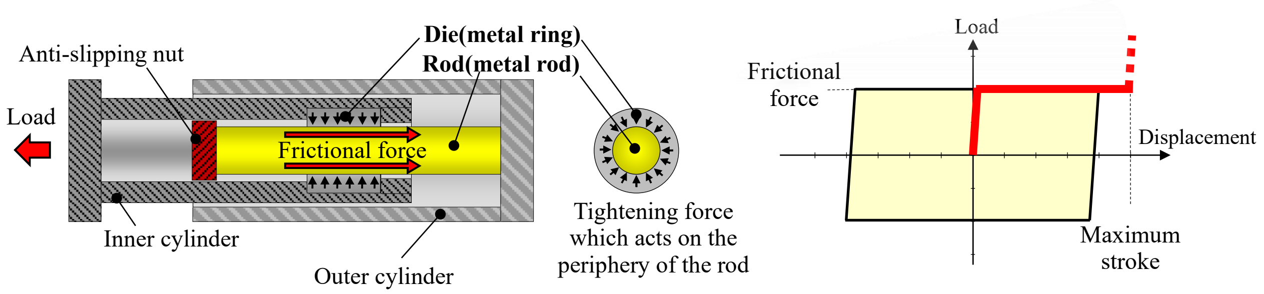
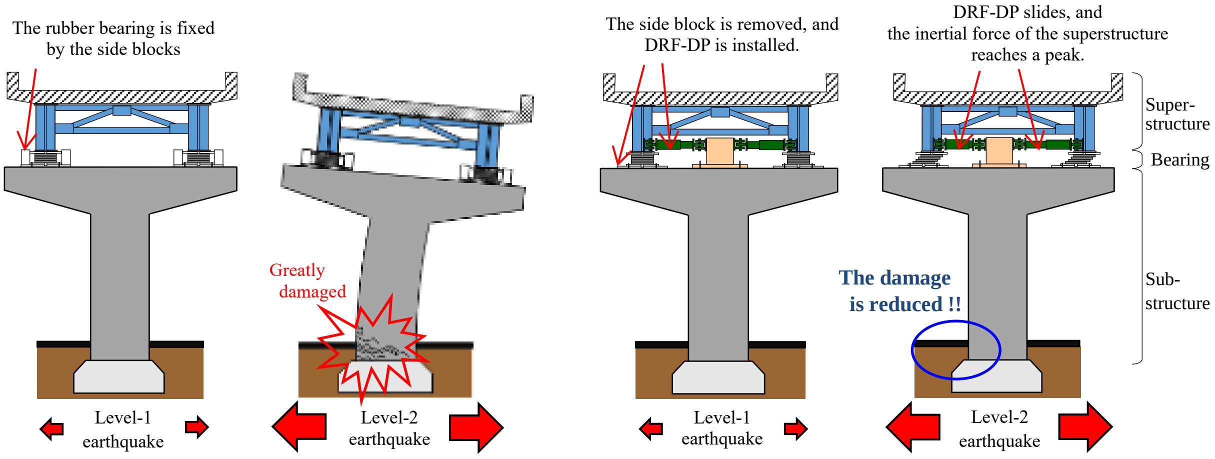


Fig.1 - Method of seismically reinforcing a bridge using friction dampers



(a) Friction mechanism (b) Rigid-plastic hysteretic characteristic

Fig.2 - Outline of DRF-DP



(a) Before reinforcement (b) After reinforcement

Fig.3 - Conceptual illustration showing the effectiveness of seismic control using this method

are displaced with constant frictional force. This is known as the rigid-plastic hysteretic characteristic (Fig.2).

3. Scope of Application

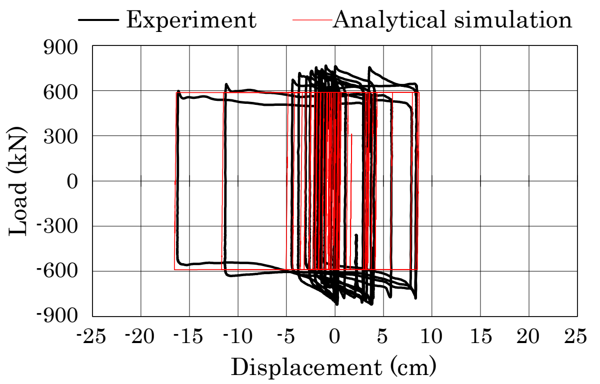
DRF-DPs are installed in existing road bridges. They are so compact that they can be installed in narrow spaces at the crown or side of the bridge pier. One end of DRF-DP is fixed at the crown of bridge pier and the other end at the side of bridge girder.

4. Effect of Developed Technology

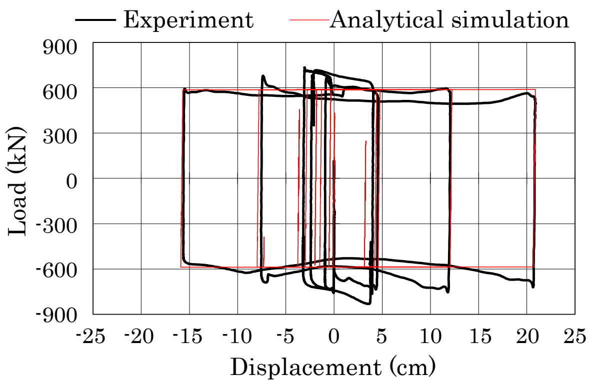
The strength of the DRF-DP lies on its rigid-plastic hysteresis characteristic (Fig.3). It does not slide during level-1 earthquakes (which are defined as small to medium earthquakes that are highly likely to occur (Japan Road Association 2012)). Due to this characteristic, DRF-DP acts as a substitute for the side block which restrain bearing displacement (left sides of Fig.3 (a) and (b)). On the other hand, it slides during level-2 earthquakes (which occurs less frequently but are expected to cause serious damage to bridge piers (Japan Road Asociation 2012)). As a result, DRF-DP sets a limit to the inertia force of the superstructure. Furthermore, it absorbs seismic energy efficiently to reduce the response of the substructure (right sides of Fig.3 (a) and (b)).

DRF-DPs applied at the bearings of road bridges are assumed to be displaced with a high amplitude exceeding 10 cm at a high speed of 100 cm/sec or greater. Thus, we verified that DRF-DP exhibited the rigid-plastic hysteretic characteristic and steadily absorbed energy under such severe conditions in a high-speed excitation experiment (Pic.1). Fig.4 shows comparison between the results of experiment and analytical simulation. Fig.4(a) and (b) display that DRF-DP exhibited the rigid-plastic hysteretic characteristic similar to that in the analytical simulation during the two type earthquakes, although the load of DRF-DP tended to increase slightly at low amplitude. Fig.4(c) describes that the energy time history obtained in the

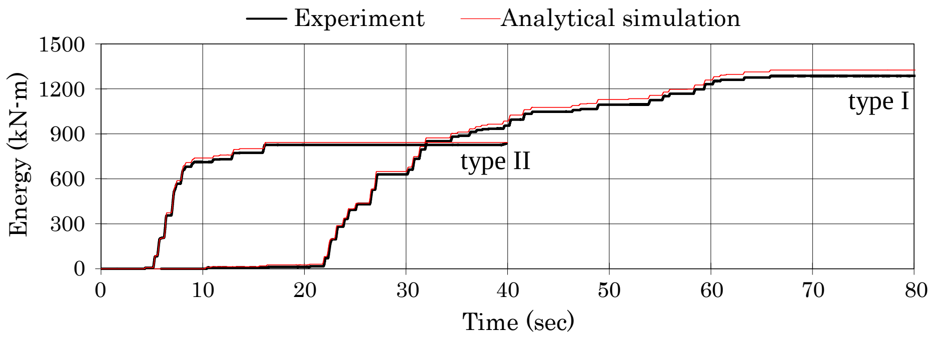
Pic.1- General view of excitation experiment



(a) Load-displacement (Great East Japan Earthquake)



(b) Load-displacement (Kobe Earthquake of 1995)



(c) Energy absorption time history

Fig.4 - Results of excitation experiments

experiment was in agreement with that in the analytical simulation. It was thus verified that DRF-DP could absorb energy as expected against level-2 earthquake motions. The Dependency and the durability of the DRF-DP when subjected to repetitive earthquakes were also verified in the experiments.

A large-scale shaking table test was conducted to confirm the behavior of the entire RC pier using DRF-DPs (Pic.2). This experimental model is based on the RC single column bridge pier currently used on the Metropolitan Expressway. Fig.5 shows the response displacements of the pier before and after reinforcement. It was found that the installation of DRF-DPs reduced the maximum response value from 26 mm to 11 mm.

Pic.2 - Shaking table test situation

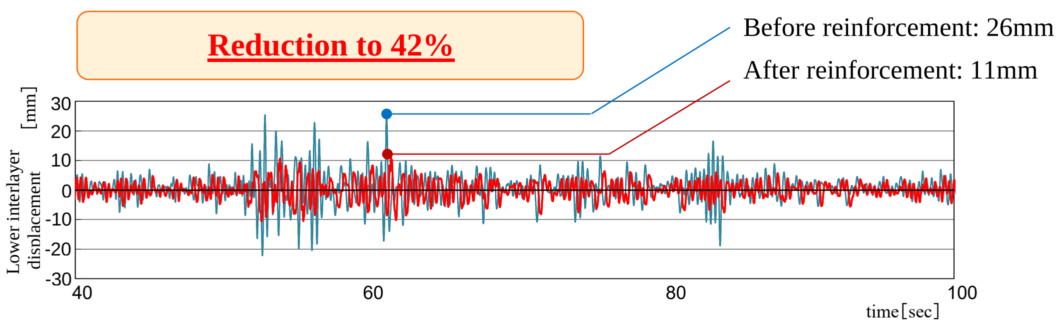


Fig.5 - Response displacement time history of pier (Great East Japan Earthquake)

5. Installation Record

Seismic retrofitting of bridges with rocking piers are urgently required in Japan ever since some of them collapsed due to the 2016 Kumamoto Earthquake. In 2020, Metropolitan Expressway installed DRF-DPs (two 650 kN dampers and four 1000 kN dampers) in the rocking piers of Route No.11 Daiba Line for seismic retrofitting (Pic.3). DRF-DP was applied to one of specifications for the design and construction guidelines of Metropolitan Expressway.

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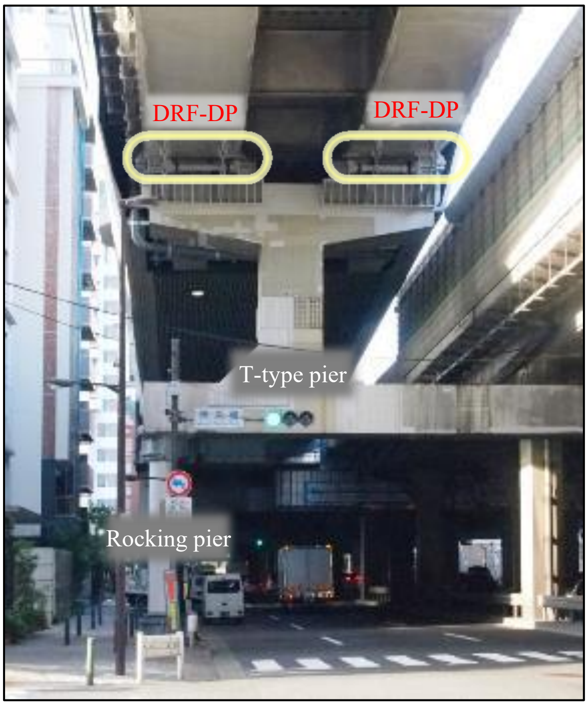
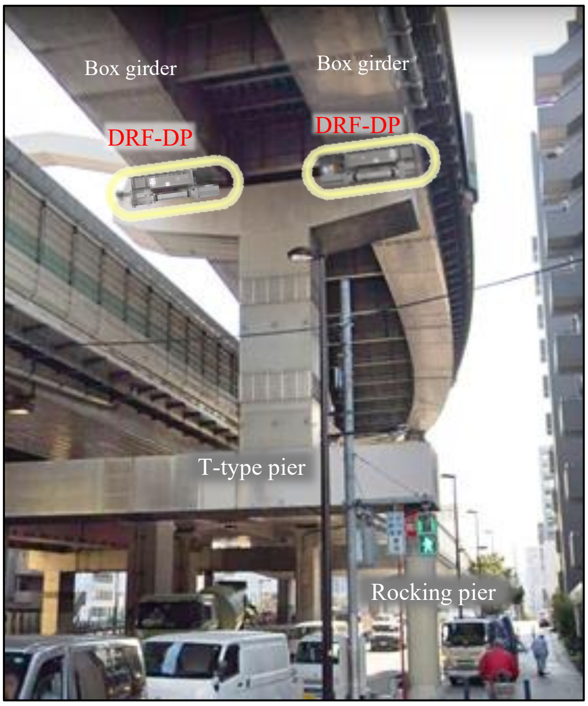
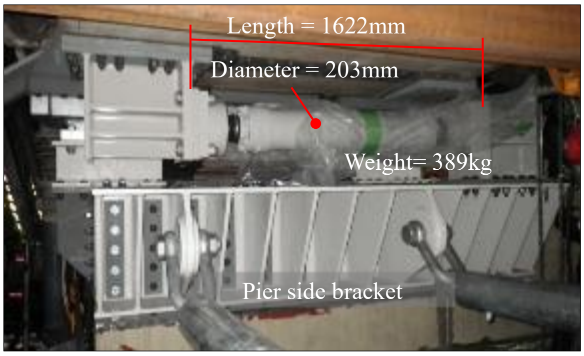


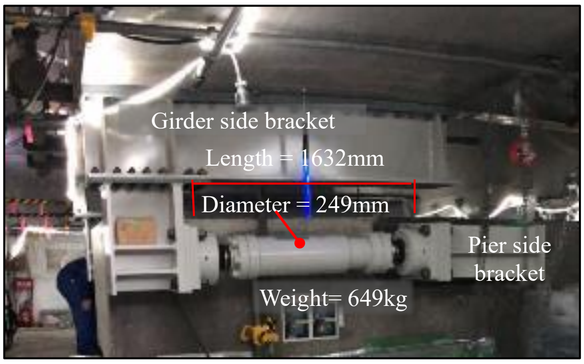
(a) General view (650kN DRF-DPs)



(b) General view (1000kN DRF-DPs)



(C) Installed 650kN DRF-DP's position
(Crown of the pier with bracket)



(d) Installed 1000kN DRF-DPs position
(Side of the pier with bracket)

Pic.3 - Installed DRF-DPs

1） . INTRODUCTION

STEIN, a high-quality inorganic soil-hardening agent, was developed by a Japanese engineer named Mr. Takao Matsumura in 1975. Around that period, Mr. Matsumura worked at Honda Motor Co., Ltd. At first, he developed STEIN for preventing the elution of heavy metals such as hexavalent chromium and arsenic in concern of environmental protection. It fixed heavy metals in the soil through a chemical reaction known as the Pozzolanic reaction and hydration. After realizing how STEIN could be used for road constructions due to its function of hardening soil into a strong and solid mass, he started manufacturing STEIN in Hokkaido, his hometown in Japan, utilizing it for the improvement of construction works for roads and rivers. Using STEIN is very simple. The process involves mixing on-site soil with an appropriate amount of water and STEIN.

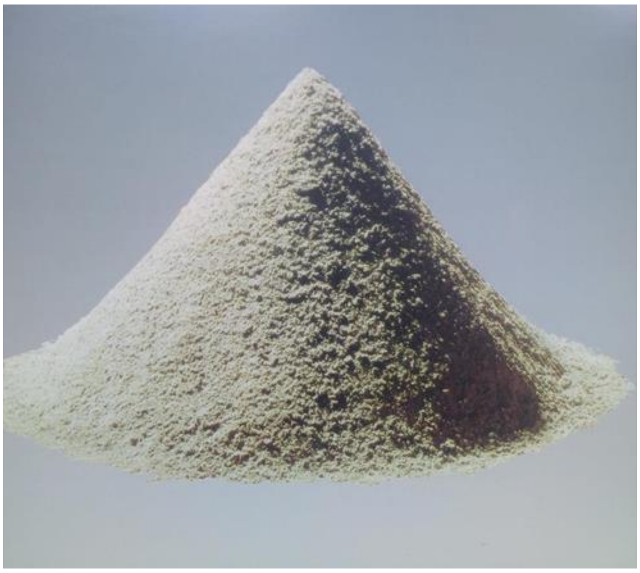


Photo 1 STEIN is a powder-type soil hardener

2） DETAILS ABOUT STEIN

STEIN consists of two factors, STEIN elements, which are composed of 27 inorganic additives such as Mg, Ca and Al, and Portland cement. By mixing 5% of STEIN element and 95% of ordinary cement, STEIN, an environmentally friendly soil hardener, is created. It can be utilized to create a robust structure in a short period of time by mixing it with on-site soil and water, later rolling it down to the land surface. STEIN can be used flexibly according to the condition of the soil by adjusting the percentage of the STEIN against soil. It is used in over 1,500 public work projects such as irrigation riverbeds improvement, farm roads construction, etc., conducted by the Ministry of Agriculture, Forestry and Fisheries, the Ministry of Defense, and many local government bodies in Japan. STEIN elements are also exported to various countries in South-east Asia (Malaysia, Thailand, Myanmar, Indonesia, the Philippines, Sri Lanka, Cambodia), East Asia (China, Korea, Taiwan), America(USA), Europe(Italy, Germany) and Africa (Kenya).

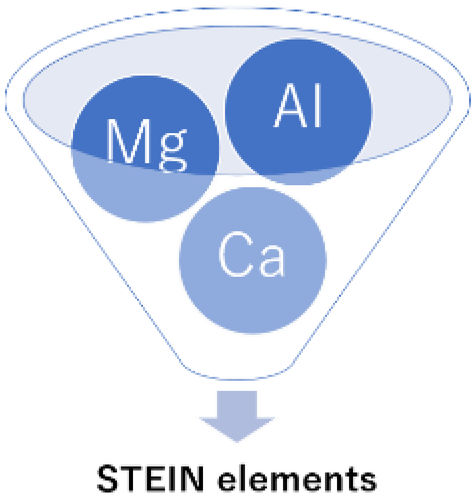


Figure 1 STEIN element

3) CONSTRUCTION PROCESS OF STEIN

Before construction, we inspect the soil in the project site and conduct mixture tests with STEIN. These tests for soil analysis include measuring the moisture content, density of soil particle, wet unit weight, grain size, and liquid and plastic limits. There are also tests performed to measure the moisture density of the final mixture rate between soil and STEIN. After 7 days of measuring, we conduct a strength test by testing the pieces with different mixing rates of the STEIN and on-site soil to determine the best mixing rate. The construction process of STEIN is very simple, as shown below.

1) Spreading STEIN over the land surface

2) Mixing of STEIN with soil

3) Compaction

4) Watering and curing

5) Completion

The construction site can be opened for traffic after 24 hours of completion. This is one of the biggest advantages of STEIN, as the roads can be opened after a short period of time.

4) EFFECT OF USING STEIN

Regarding the soil strength for roads, it depends on the type of soil and mixture rate of STEIN. Our first target is 30kgf/cm² in a week after construction, and in two weeks later, the strength of mount sand mixture and laterite mixture can reach up to 60kgf/cm². (Fig. 2) Vehicles with the wheel loads of 6.8kgf/cm², for example, will be able to pass the roads constructed with STEIN.

The durability of roads using STEIN-mixed soil has another big advantage; they need less maintenance. We set the goal of the life span of roads to be 20 years, preserved with minimal maintenance. The longest life span was 45 years, which is located in Hokkaido, one of the most cold and snowy areas of Japan.

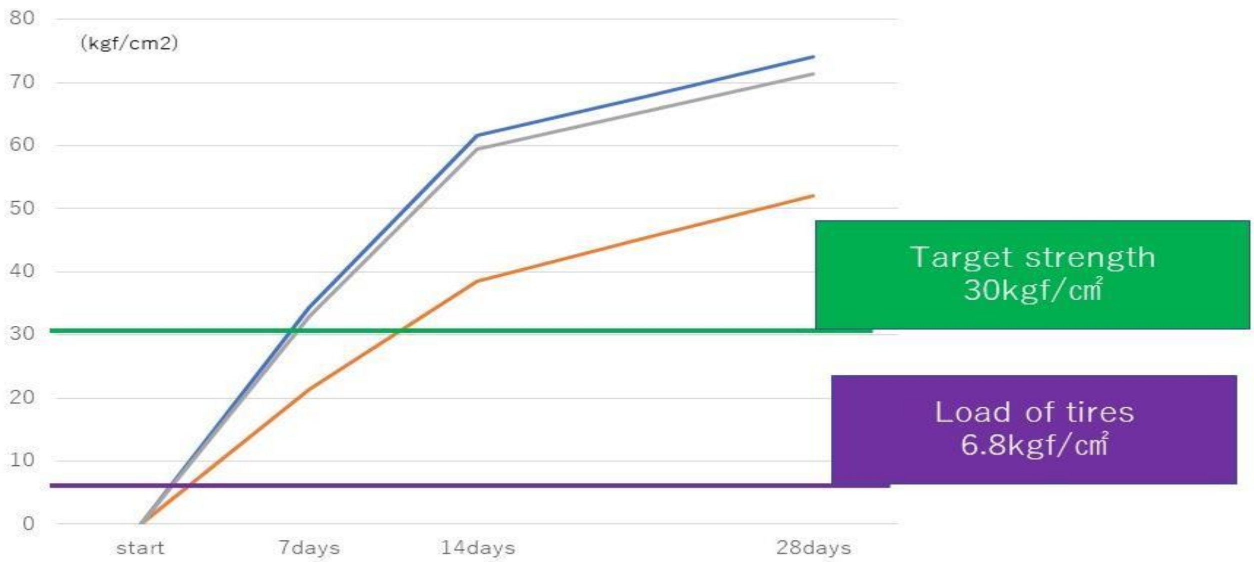


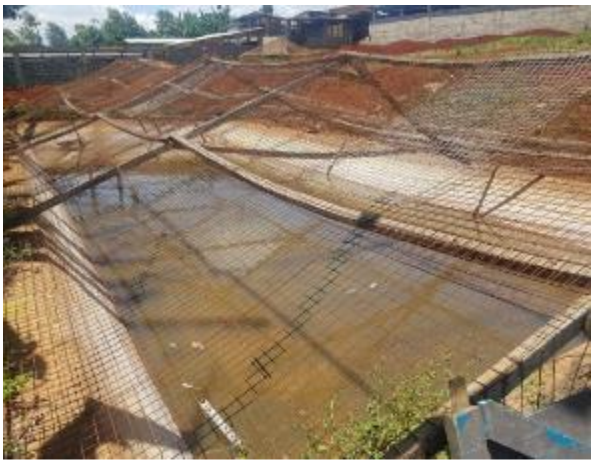
Figure 2 Result of the strength test

As a result, we would like to emphasize that STEIN can make road construction simpler (without reinforcing bars, etc.), with a lower cost (40 to 60% more reasonable than asphalt roads). Furthermore, STEIN gives the soil high durability, which can lessen road maintenance activities.

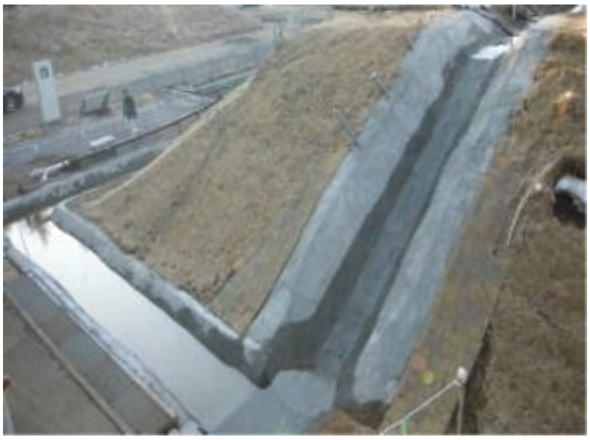
5) EXAMPLES OF CONSTRUCTION

1) A farm road located in Hokkaido. This road was constructed in 1975 and functions as a waterway after the snowy winter.

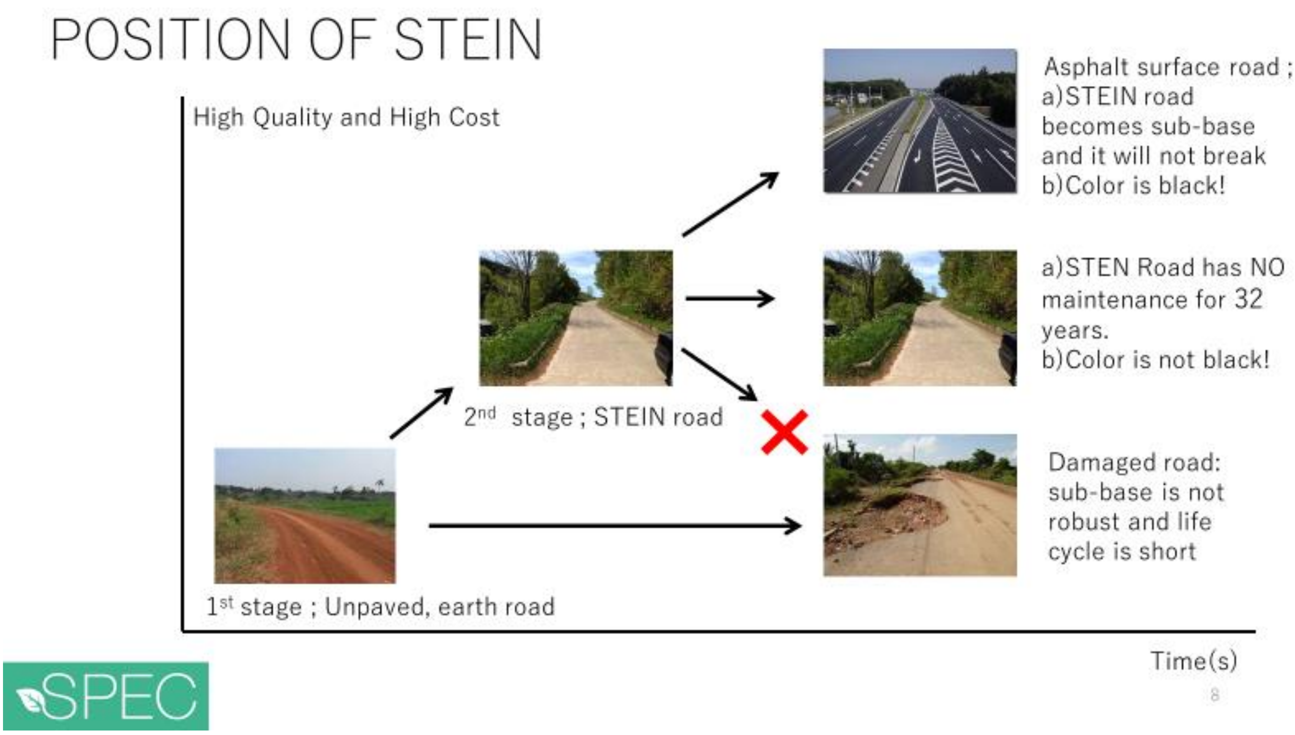
2) A water pond with its slopes covered by STEIN mixed soil to prevent soil erosion in Kenya.



3) Spill ways of water ponds that prevents flood disaster caused by heavy rains.



4) Park roads of local and national parks, school playground, etc.



6) APPLICATION OF TECHNOLOGY

Today, in Japan, weed prevention treatment on roadsides are required to reduce cost, time and labor of road maintenance, which is repeatedly conducted every year. The roots of weed cannot grow if the soil load is over 30kgf/cm², and thus STEIN is a good solution to this issue, as the strength of the STEIN roads become more than 30kgf/cm². (Fig. 3)

In the middle of February 2020, we constructed a test site in Japan.

Condition of roots	Easy to grow	Possible to grow	Difficult to grow	Impossible to grow
Strength (kgf/cm²)	0-10	10-20	20-30	More than 30

Figure 3 Relationship between the strength of surface and condition of roots

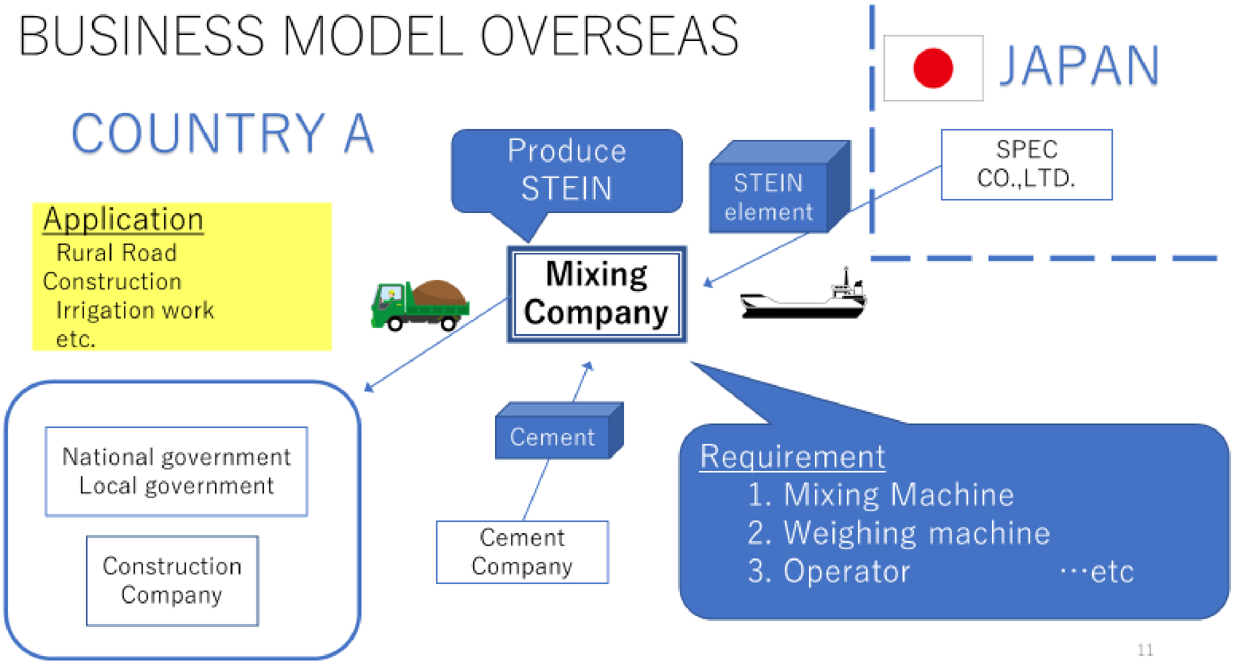
Before construction

After construction

7) BUSINESS MODEL OF STEIN

In most cases of construction work abroad, we ship the STEIN (STEIN elements and cement) from Japan. However, the main component of STEIN is ordinary cement, and thus it is possible to use each country's local cement to make STEIN more accessible. We export STEIN elements from Japan and ask local mixing companies to mix it with machines.

During the construction process, the cooperation of local road construction companies is also essential for conducting constructions. Moreover, our relationships between national and local governments, stakeholders and contractors are also important to conduct the road and/or irrigation projects.



8) THE FUTURE OF STEIN

We are confident about the possibility of STEIN; we believe that it can significantly contribute to the development of infrastructure. Although the STEIN elements are strictly mixed in a factory in Japan, Portland cement is available all over the world, and thus our next goal is to establish a manufacturing plant abroad. We plan to not only sell STEIN, but also to make an opportunity for people to work with and learn the technology about construction projects using STEIN. We hope that our knowledge and know-how of STEIN will be passed on to future generations.

Here below is the contact information of SPEC COMPANY LIMITED.
If you are interested in our product, please feel free to contact us.
Lastly, we greatly appreciate the opportunity of writing for IDI Quarterly.

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Infrastructure Development Institute-Japan (IDI) is a general incorporated association operating under the guidance of Ministry of Land, Infrastructure, Transport and Tourism of Japanese Government.
IDI provides consulting services to facilitate International Assistance to developing countries, to promote international exchange of information and human resources, and to support globalization of project implementation systems targeting both developed and developing countries in the field of infrastructure.

IDI has been publishing the free quarterly journal called "IDI Quarterly" since1996 to introduce information related to public works and construction technologies developed in Japan to foreign countries. We have distributed the journal to administration officials in more than 90 countries around the world by e-mail.

It is highly appreciated if you would send us your opinions, impressions, etc. on the articles.
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