補強土工法のためのフェロセメン要素の設計に関する研究
(Design of Ferrocement Elements for Soil Reinforcement)

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Introduction: The development of ferrocement elements with enough tensile resistance provided by the steel wire mesh and enough frictional resistance provided by the interfacial friction between the cement mortar and backfill can be a significant reinforcing material for reinforced soil structures as compared to conventional reinforcements. A thorough investigation on the ferrocement-soil interface characteristics, ferrocement surface resistance, mortar cracking behavior and wire mesh failure behavior is indispensable for cost-effective application of ferrocement elements in reinforced soil structures. It should be pointed out here that in spite of the volume of information available, little or no research work is reported in the literature in this concern.　In this paper, an attempt is made to understand the pullout behavior and shear behavior of ferrocement-soil interface, to determine the surface strength properties of ferrocement elements and to examine the failure mechanism of the individual ferrocement elements. From the pullout and shear tests results, the behavior and analyses of the failure mechanism of the ferrocement elements and development of the technique are reported in this paper.

Design consideration: For effective design of ferrocement elements to use in soil reinforcement, four possible modes of failure of ferrocement elements can be considered as given in Figs. 1-4. Fig.1 shows the shear or pullout failure between soil and ferrocement element. If the interfacial friction between ferrocement and soil is less than the shear or pullout force but is more than the tensile capacity of mortar and mesh then this mode of failure occurs. Therefore, this mode of failure depends on the ferrocement surface properties. Fig.2 shows the mortar failure of the ferrocement elements where the shear or pullout force exceeds the tensile stress of mortar but is less than the frictional resistance and tensile capacity of ferrocement. Fig.3 indicates the mesh failure of ferrocement. This case occurs when the tensile capacity of mesh is less than the frictional capacity of ferrocement-soil interface. In Fig.4, the bond failure between mesh and mortar is shown. This happens when the bond force between the mesh and mortar is less than the pullout or shear force, frictional resistance of ferrocement-soil interface and tensile capacity of mesh.

Materials and methods: Ordinary Portland cement and river sand passing through No.8 (2.38mm) sieve, having a fineness modulus of 2.33, were used for casting. The square mesh and hexagonal wire mesh obtained from the market was cut to obtain the desired size.

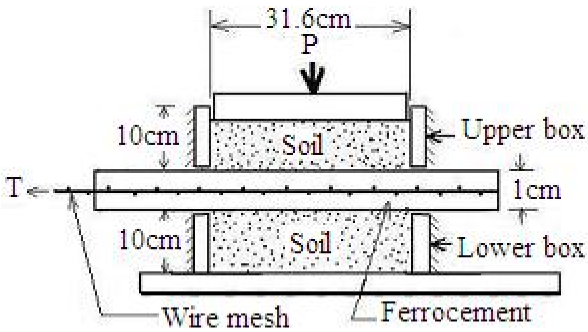

Fig.1 Shear or pullout failure

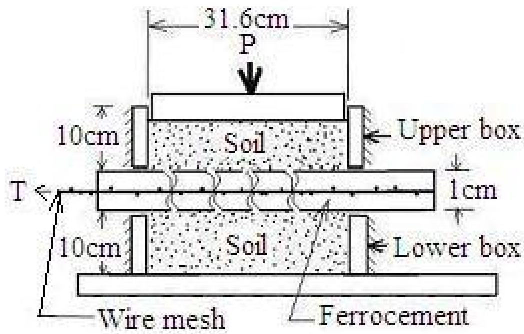

Fig.2 Mortar failure

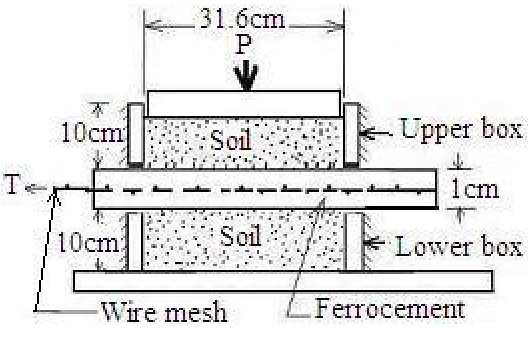

Fig.3 Mesh failure

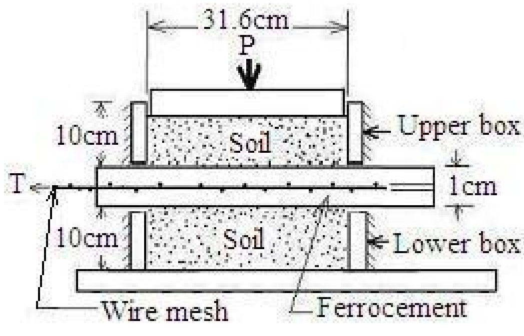

Fig.4 Bond failure

＊　三重大学生物資源学部, Faculty of Bioresources, Mie University;　「フェロセメント、せん断強度、引抜き強度」

The diameter of wire was 1.0 mm with center-to-center opening of 10.0 mm for square mesh and the wire diameter of chicken mesh was 0.8mm. Ferrocement elements with ordinary plain surfaces and rough surfaces were made by small channels of varying number (Fig.5). The thickness and size of the ferrocement elements are 10.0 mm and 31.5×38.0 mm, respectively. The properties of sandy and clayey soils used in these tests are depicted in Table 1. The shear tests were carried out in the way of pushing out the element along with the lower box from the soil with constant selected speed by means of screw jack under electrically operated constant pressure. The pullout tests were carried out by pulling out the ferrocement element while both the upper and lower boxes were being fixed. The shear and pullout forces were measured using a tension load cell with the least count of 5N. The displacements were measured by means of a dial gage with least count of 0.001mm.


Fig. 5 Ferrocement with smooth and rough surfaces

Table 1－Properties of soil

Component	Parameter	Sandy soil	Clayey soil
Dry unit weight	γ_d	1.83 t/m^3	1.53 t/m^3
Optimum water content	w_{opt}	15.3%	25.0%
Specific gravity	ρ_s	2.64	2.70
Cohesion(kPa)	c	5.01	64.30
Angle of internal friction	ϕ	32.19^o	16.01^o
Sand, >75μm		78%	34%
Silt, 5-75μm		13%	33%
Clay, <5μm		9%	33%
Liquid limit	w_L	-	56.2%
Plastic limit	w_p	-	29.3%
Plasticity index	I_p	-	26.9

Results and discussion: For the sake of clarity towards the cost effective and optimum design of ferrocement elements, different modes of failure of the ferrocement elements under shear and pullout tests in sandy and clayed soils are depicted in Table 2. It is evident that the failure mode depends on the ferrocement-soil interface shear and pullout resistance which is relevant to the surface characteristics of the ferrocement, strength of the mortar/matrix which is relevant the cement/sand ratio and the tensile capacity of the mesh which is relevant to type of mesh. The rate of increase of the ultimate shear and pullout strength for the ferrocement element with rough surfaces is more than that of the ferrocement element with smooth surfaces in both types of soils. The ferrocement element with rough surfaces in clayey soil and smooth surface in sandy soil show higher ultimate shear and pullout strength. This may be the effect of surface roughness of the ferrocement elements, more frictional resistance of sandy soil and more cohesion of clayey soil.

Conclusions: For all the shear tests, only the frictional failure between ferrocement and soil are observed for any types of mesh and surface characteristics of ferrocement elements. For the pullout tests, failure modes varies widely depending on the pullout stress, type of soil and type of mesh as well as surface characteristics of the ferrocement elements.

Table 2 Ultimate load and failure modes for ferrocement (c/s ratio 1:2)

	Ultimate shear stress, kPa				Ultimate pullout stress, kPa				
	Applied normal stress, kPa	Sandy soil	Clayey soil	Failure mode (both mesh)	Applied normal stress, kPa	Sandy soil	Clayey soil	Failure mode square mesh	Failure mode chicken mesh
plain surface	80	45.7	39.4	Frictional	40	61.1	58.9	Frictional	Frictional
	120	81.1	78.5	Frictional	60	90.9	87.2	Frictional	Frictional
	160	97.0	95.1	Frictional	80	121.2	115.6	Frictional	Mortar
	200	147.0	140.0	Frictional	100	155.5	147.8	Frictional	Mortar
2channels	80	44.2	48.0	Frictional	40	59.5	63.3	Frictional	Frictional
	120	86.1	89.7	Frictional	60	102.4	104.4	Frictional	Mortar
	160	117.9	121.8	Frictional	80	138.0	143.4	Mortar	Mesh
	200	148.5	155.7	Frictional	100	169.3	175.6	Mortar	Mesh
4channels	80	50.4	61.6	Frictional	40	72.7	76.1	Frictional	Mortar
	120	76.8	83.9	Frictional	60	110.5	113.1	Mortar	Mesh
	160	95.0	104.7	Frictional	80	156.2	159.5	Mortar	Mesh
	200	120.7	129.8	Frictional	100	185.0	190.0	Mortar	Mesh
6channels	80	49.7	60.0	Frictional	40	90.0	95.0	Mortar	Mortar
	120	94.8	116.4	Frictional	60	135.0	147.9	Mortar	Mesh
	160	124.4	138.5	Frictional	80	171.2	178.9	Mortar	Mesh
	200	150.9	160.8	Frictional	100	197.0	205.4	Mortar	Mesh