CIVIL ENGINEERING IN ANCIENT GREECE

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- The Greeks-technomaniacs:
  - Gods-Engineers (Hēphaistos)
  - Salvation of Humankind, thanks to the godly donation of «Έντεχνος Σοφία» (Technicl Knowledge)
  - From the Mycēnian large land-reclamation works up to the first Analog Computer (the Antikythēra Mechanism)

Civil Engineering: The oldest Profession,

after hunting.

After the abandonment of caves, humans had:

– to invent artificial shelters

– to defend themselves against waters

Civil Engineering in Ancient Greece

I. Technology of Buildings
II. Bridges by Greek Engineers
III. Geotechnical Engineering
IV. Harbour Engineering
V. Water Technology
VI. Design and Construction

I. TECHNOLOGY of BUILDINGS

BINDERS and MORTARS

a. Clay mortar (Fig. 1, Fig. 2)

b. Plaster (gypsum) [Theophrastos]

c. Lime (and mixed w. ceramic fragments)

d. Pozzuolanas [5th c.BCE, Zea, Hephaesteion, Dikaiarchia]

e. Metallic binders (Fig. 3)

+ Fig. 4

Fig.1. The West-House at Akrotēri, Thēra, [Palyvou, archives of the Akrotiri excavations]

Fig.3. Large water-tight cistern at Lavrion, [Konophagos]

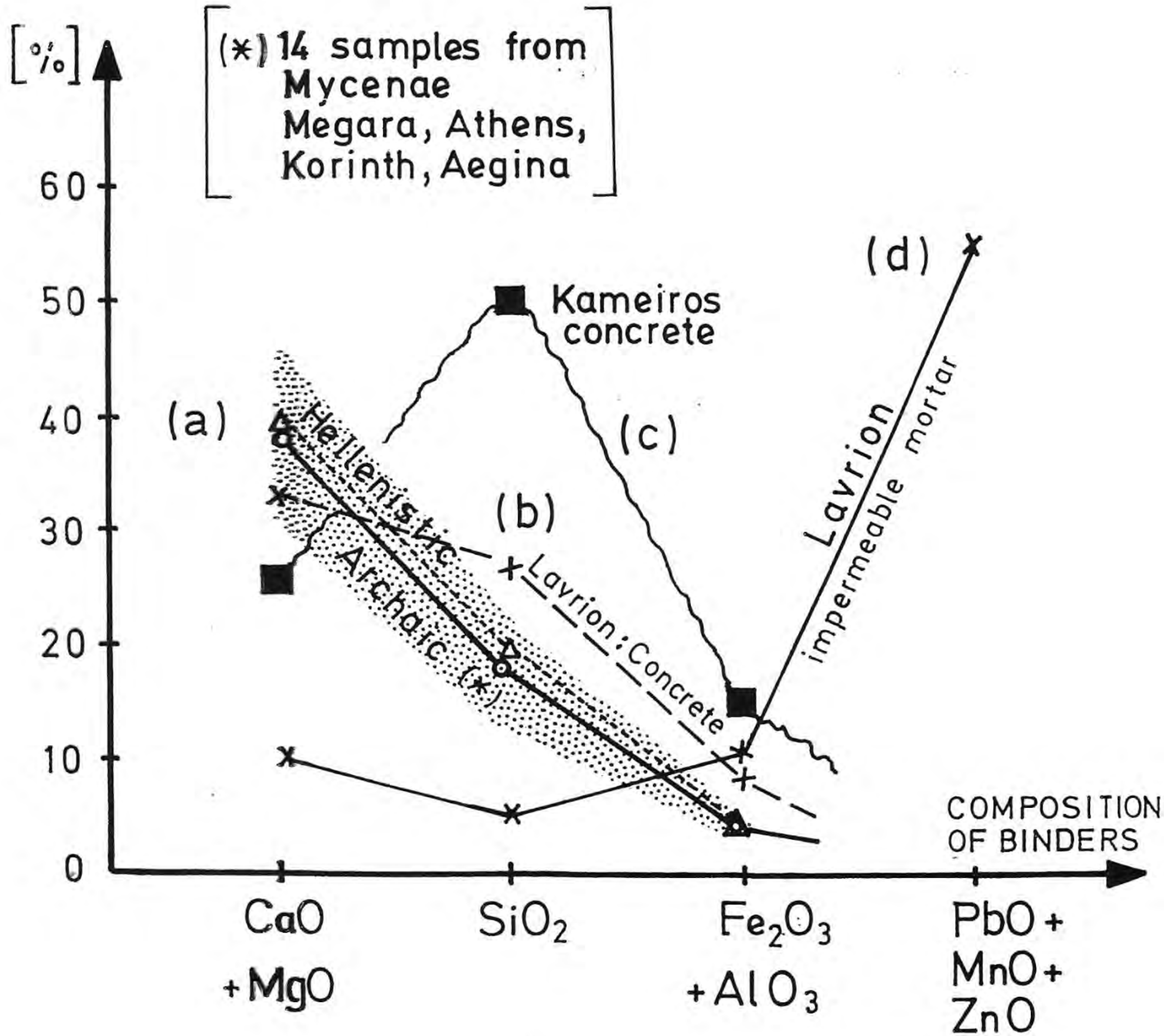

Fig.4. Chemical composition of various ancient mortars, [Author]

CONCRETE

- Lime-concrete floors, 1500 BCE (Fig. 5)
- Hellenistic villas at Rhodes (Fig. 6)
- Krēnē of Theagenēs, Megara (6^{th} c. BCE), (Fig. 7)
- Water-tank of Kameiros (4^{th} c. BCE) Strength 13,0 MPa, (Fig. 9)

23

3.

Fig.6. Rhodos: Thick, strong concrete pavement in a private villa, [Author]
Micro-concrete strong covering of the walls of the Theagenēs Krēnē, Megara, [Author]

Fig.9. The concrete-covered water-tank of Kameiros, Rhodos, (4th c. BCE), [Author]

BRICKS

a) Mud-bricks

- Akrotēri, 3-floor building
- Fortifications, (Fig. 11)

b) Baked bricks

- Inventors Euryalos + Hyperbios
- Brick kilns (fig. 12)

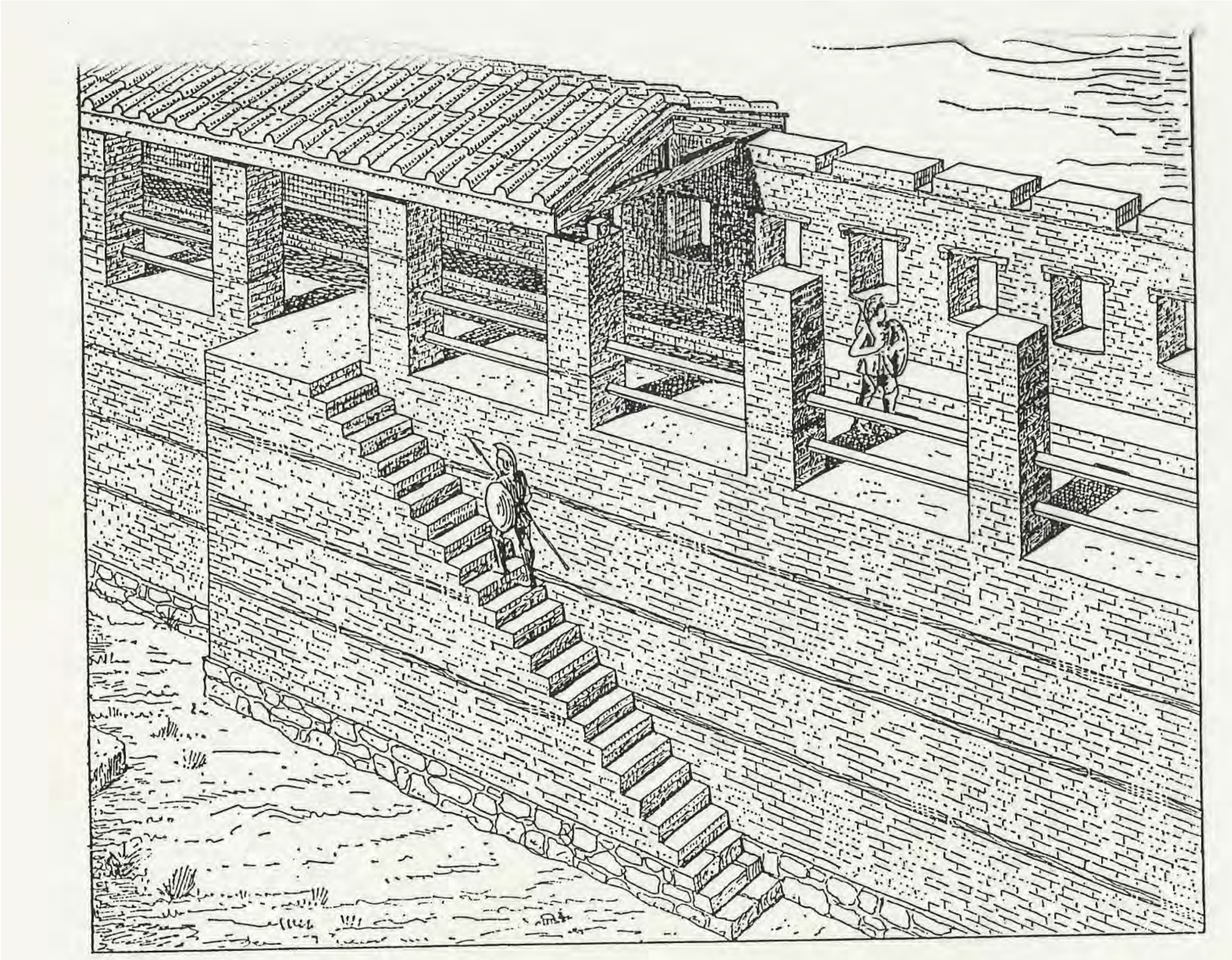

Fig.11. Mud-bricks were also used in building the fortification walls of Athens, (Orlandos)

TIMBER

- Theophrastos: Wood categories, properties, origins, manufacturing
- Roofs, (Fig. 14a)
- Masonry reinforcement, (Fig. 15)
- Aseismic hybrid system, Akrotēri (Fig. 17)
- Arsenal (Piraeus, 4th c. BCE), (Fig. 21)

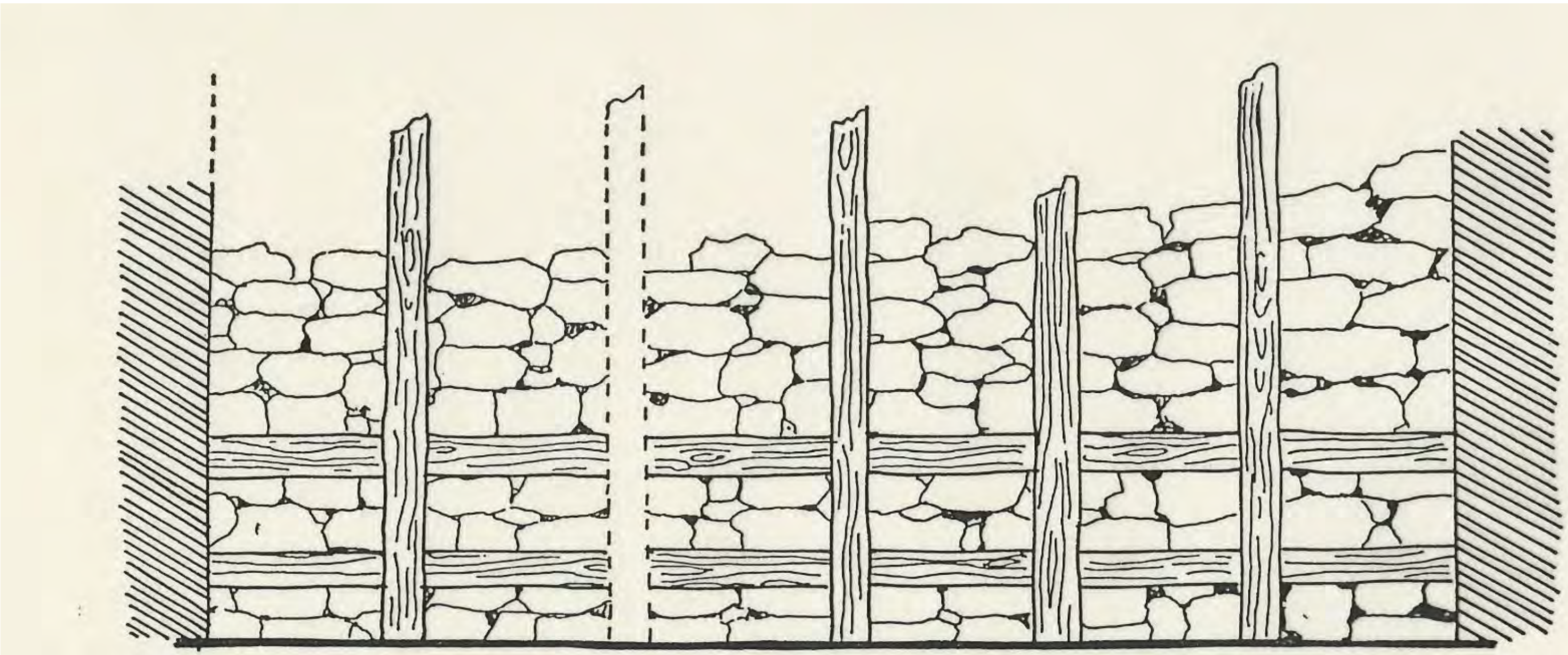

Fig.15. Spread timber reinforcement of rubble masonry, Mycenean Thēbes, (Martin)

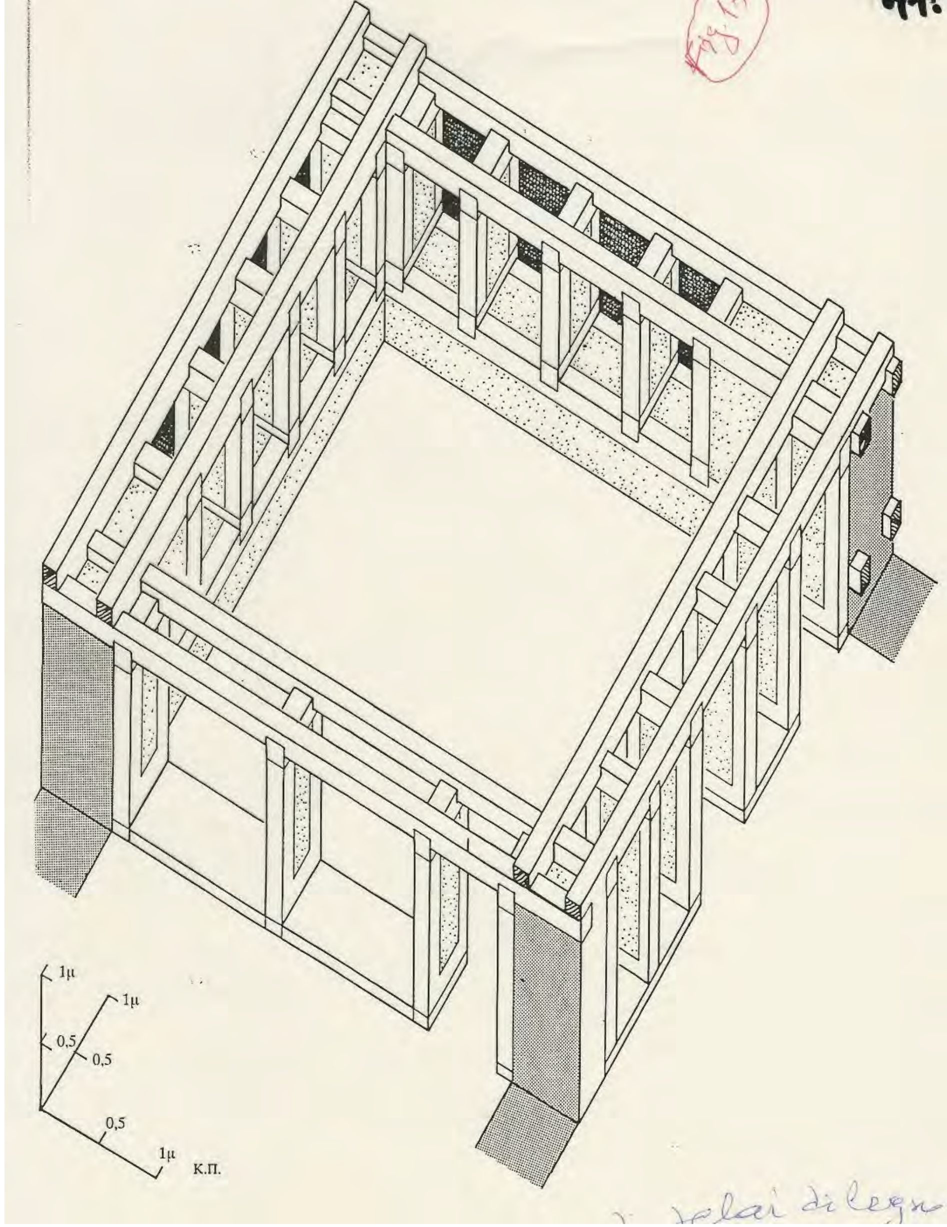

Fig.17. Complete timber frames combined with masonry, Acrotēri, (see also Fig. 16), (Palyvou)

STONES

a) Quarries

- Detailed petrographic terminology
- Ancient technical literature: Theophrastos, Diodoros, Strabon, Pausanias, Plutarch
- Penteli quarries (Fig. 24)
- Extraction (Fig. 25)
- Transportation (Fig. 26)

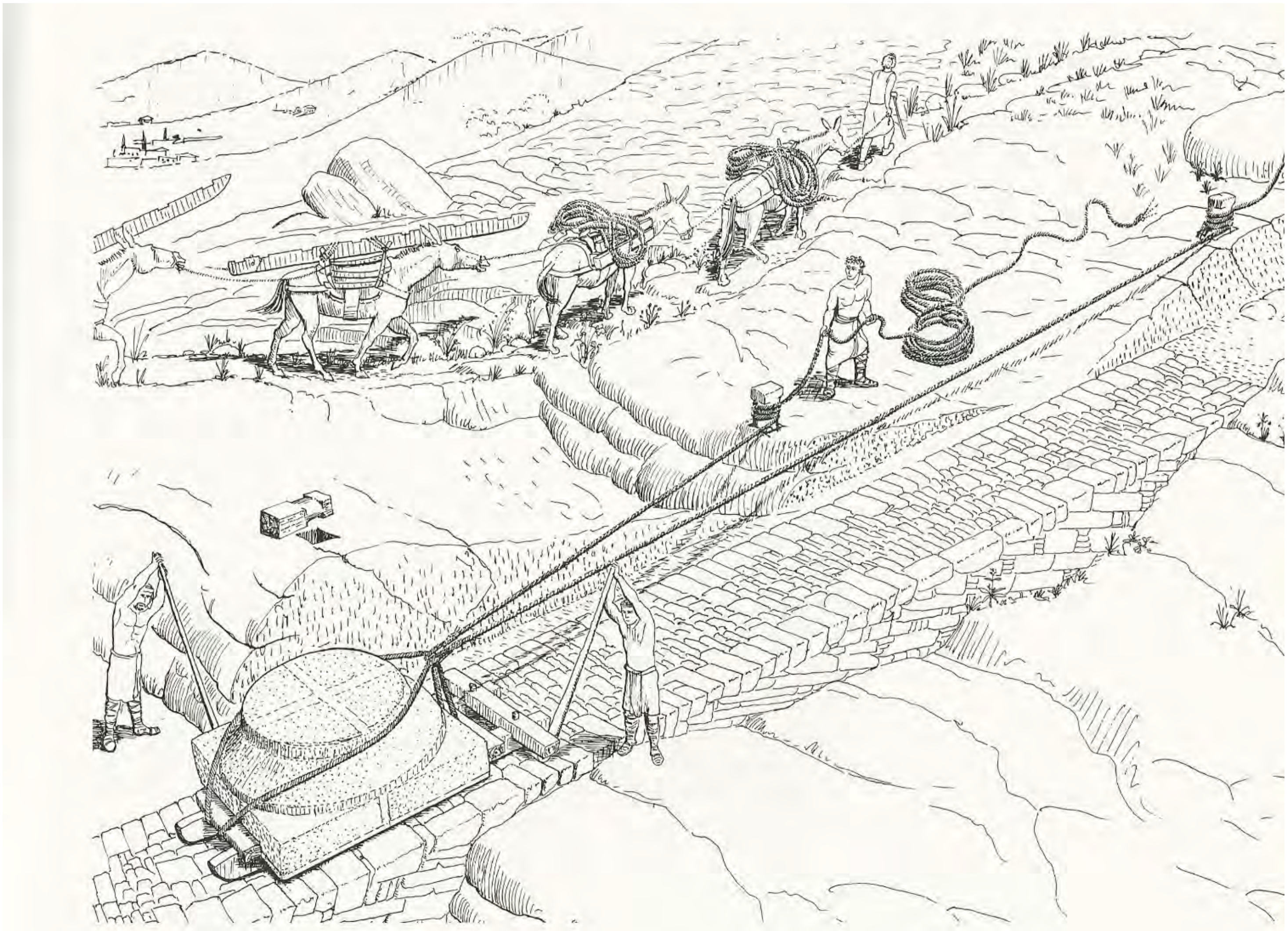

Fig.26. Sliding down of a ready-made building element from the Penteli quarries, (Korres).

b) Semi-carved and rubble masonry

- Beneficial “isodomon”, (Fig. 28)
- “Polygonial”, against shear sliding, (Fig. 29)
- Construction procedures, (Fig. 30)
- Rubble, (Fig. 31)

c) Orthogonal stones (dry joints)

(Monumental)

– Systems, (Fig. 32)
– Stone-to-stone connections, (Fig. 35)
– Robust corner connections, (Fig. 33)
– Economical “pseudo-isodomic”, (Fig. 36)

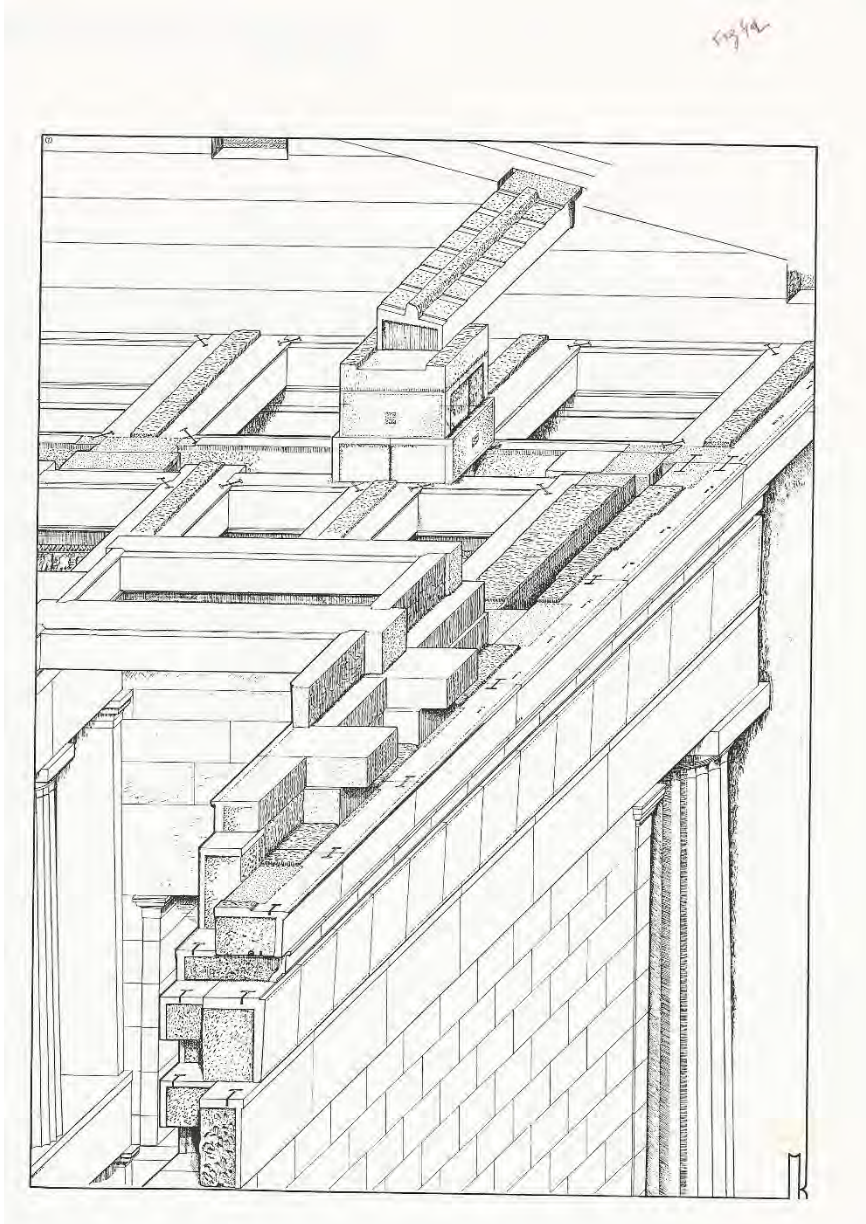

Fig.32. Completely sculptured orthogonal stones were the basic material of the monumental classical buildings, (Korres)

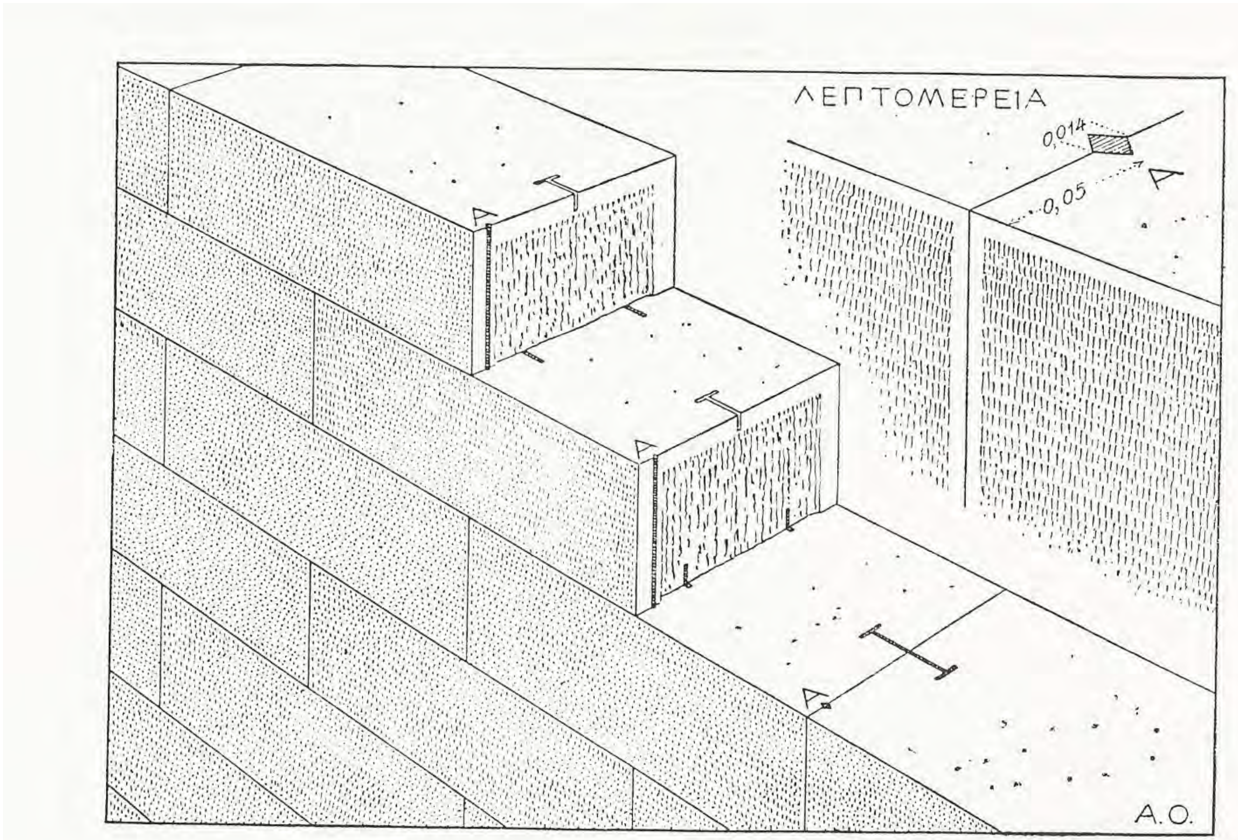

Fig.35. Systematic connections of consecutive blocks, and water tightness achieved by means of infused melted lead, (Orlandos)

d) Columns

- Monolithic, (Fig. 27)
- Drum-columns, (Fig. 37)
- Shear poles, corrosion protected, (Fig. 38)
- Stone beams, (Fig. 39)

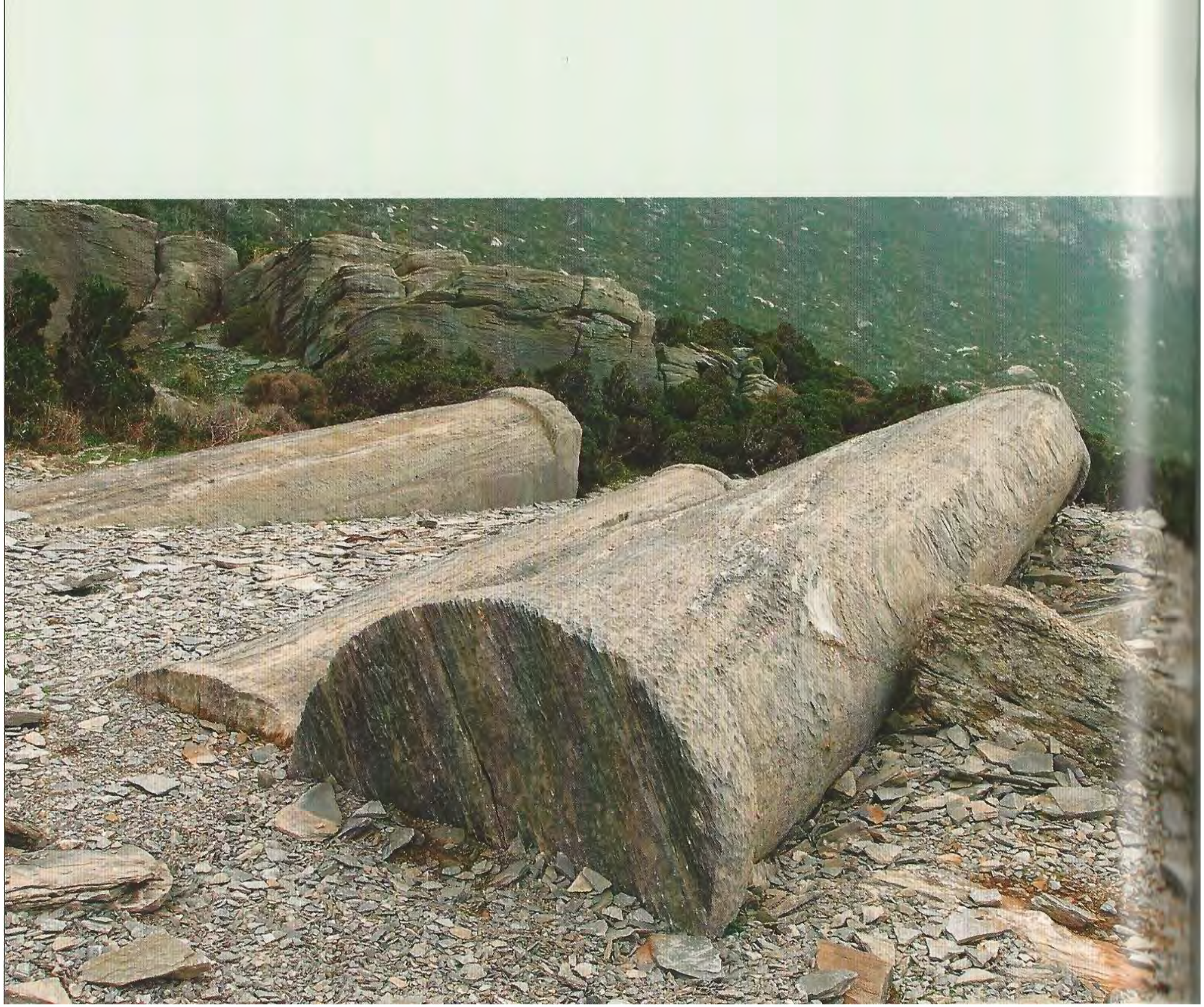

Fig.27. In situ shaped and abandoned columns in the quarries of Karystos, (Kokkorou et al.)

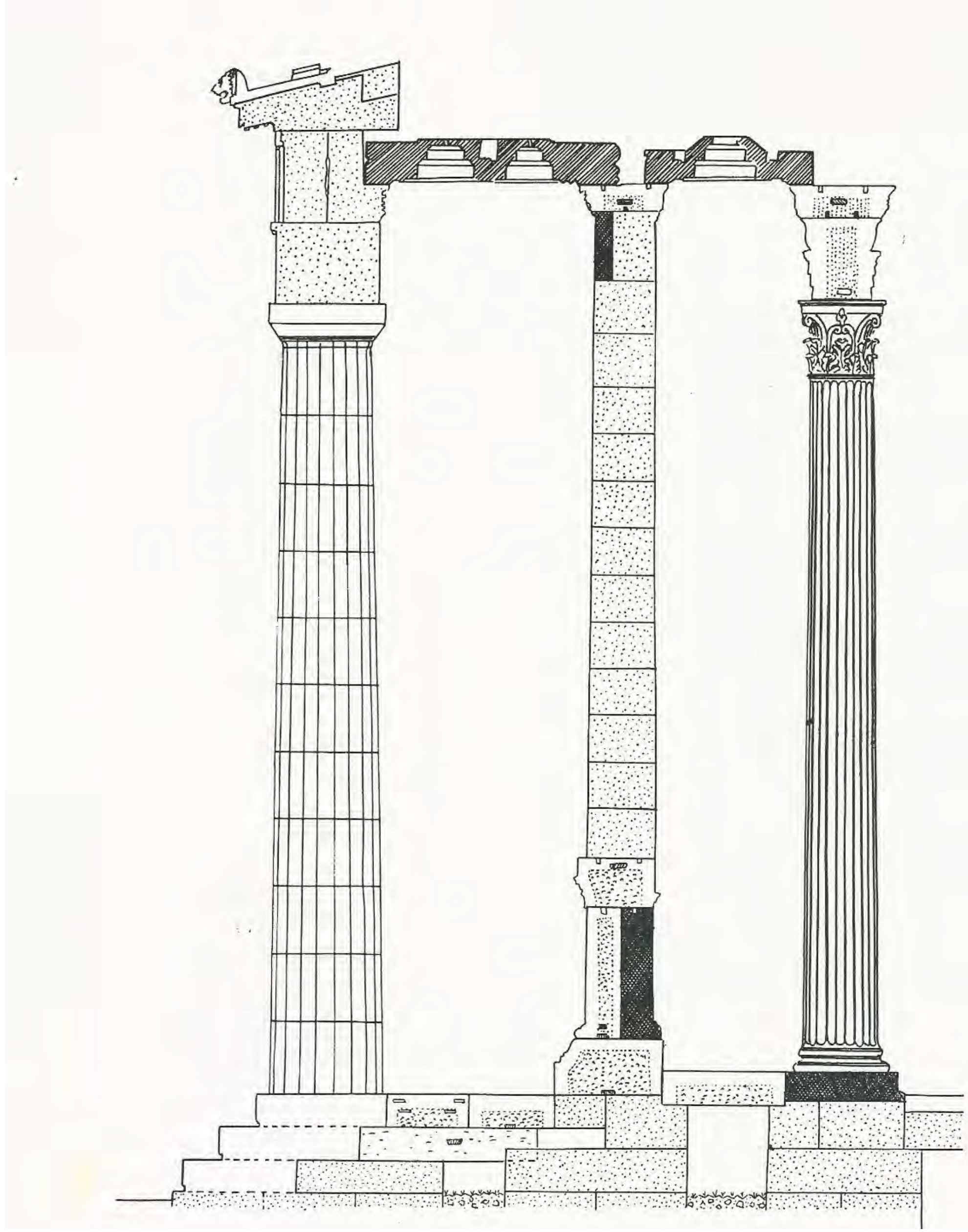

Fig.37. Cross section of the Tholos of Epidavros, (Martin)

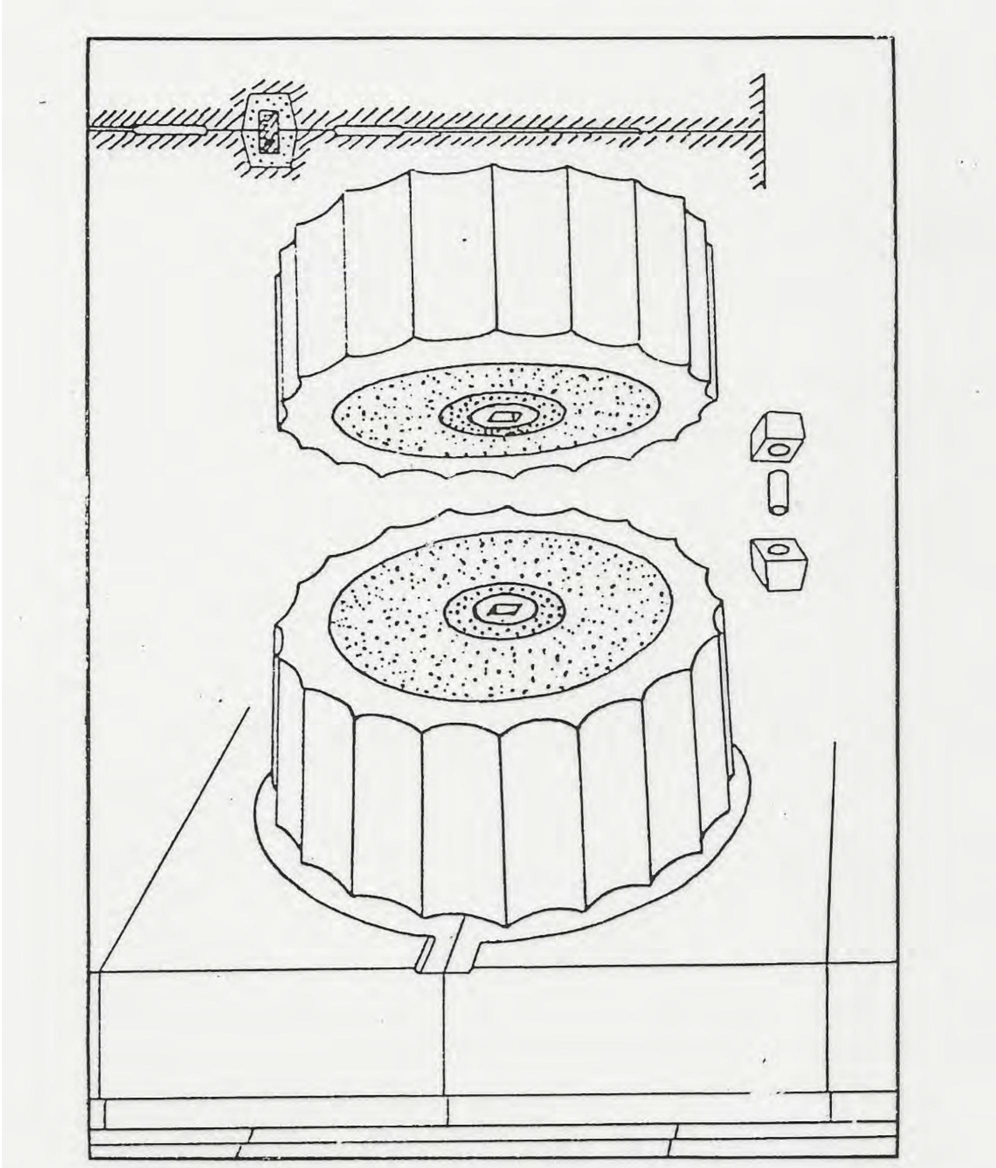

Fig.38. Column drums connected with iron poles (Penrose, in [5])

e) Three-leaf masonry

- Cross section, (Fig. 40)
- Stronger version, (Fig. 42)
- Comparative thicknesses, (Fig. 43)

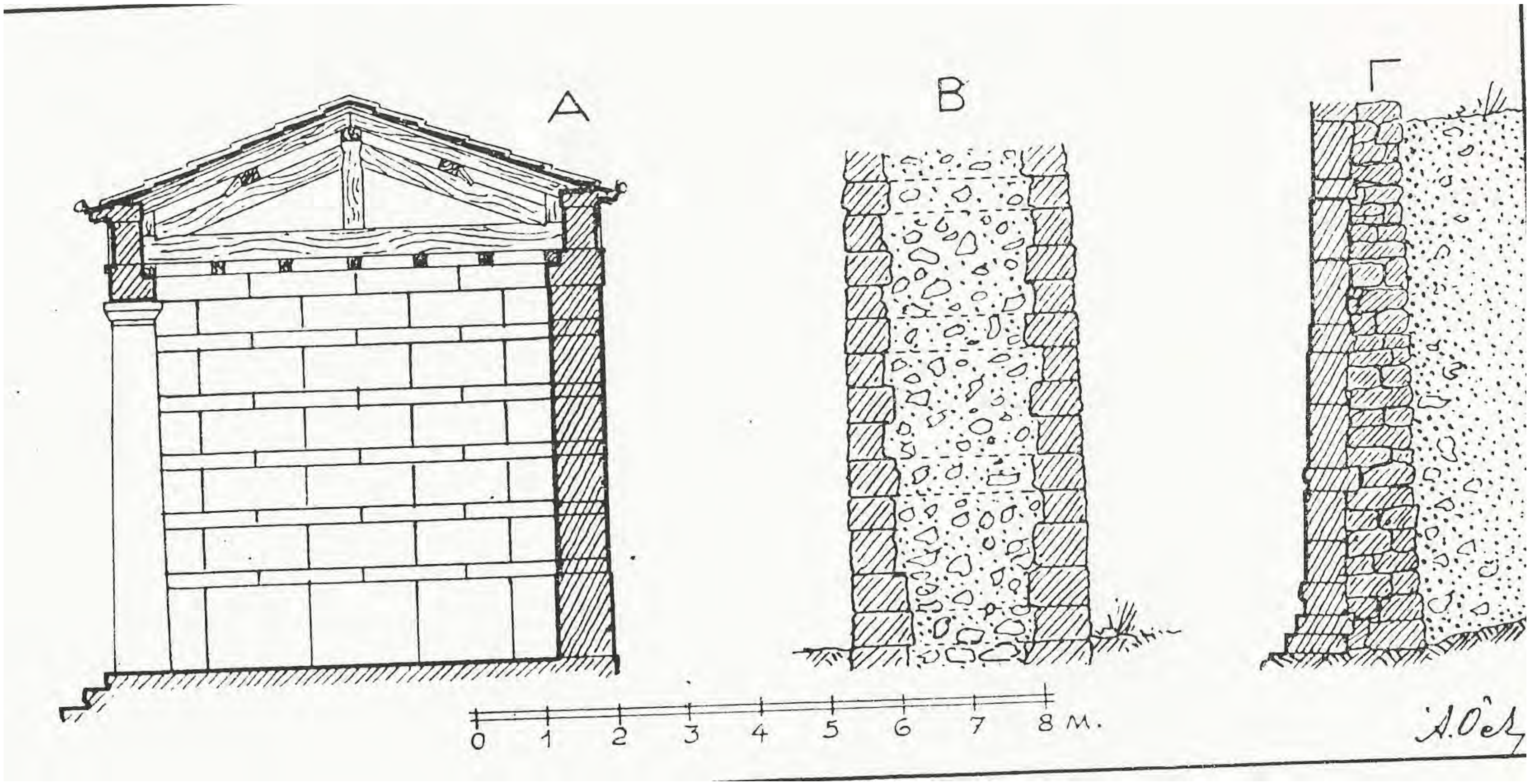

Fig.43. Comparative thicknesses of walls, (Orlandos)

f) Apses and Domes

- Pre-Roman true vaults
- Dēmocritos (460-370 BCE) studied the significance of key-stone in apses
- Oiniadae (5^{th} c. BCE), semicircular apse with key-stone, (Fig. 45)
- Assos, fortification gate, keyed apse (beg. 3^{rd} c. BCE), (Fig. 46)
- Oracle of Acheron, 4^{th} c. BCE, (Fig. 46a)

Fig.46. Vaulted gate of the fortifications of Assos, (Clarke, in [5])

h) Lifting devices

Coupled pulleys and a windlass, mounted on top of one, two, three or four timber beams

(Fig. 56, 57, 58, 59)

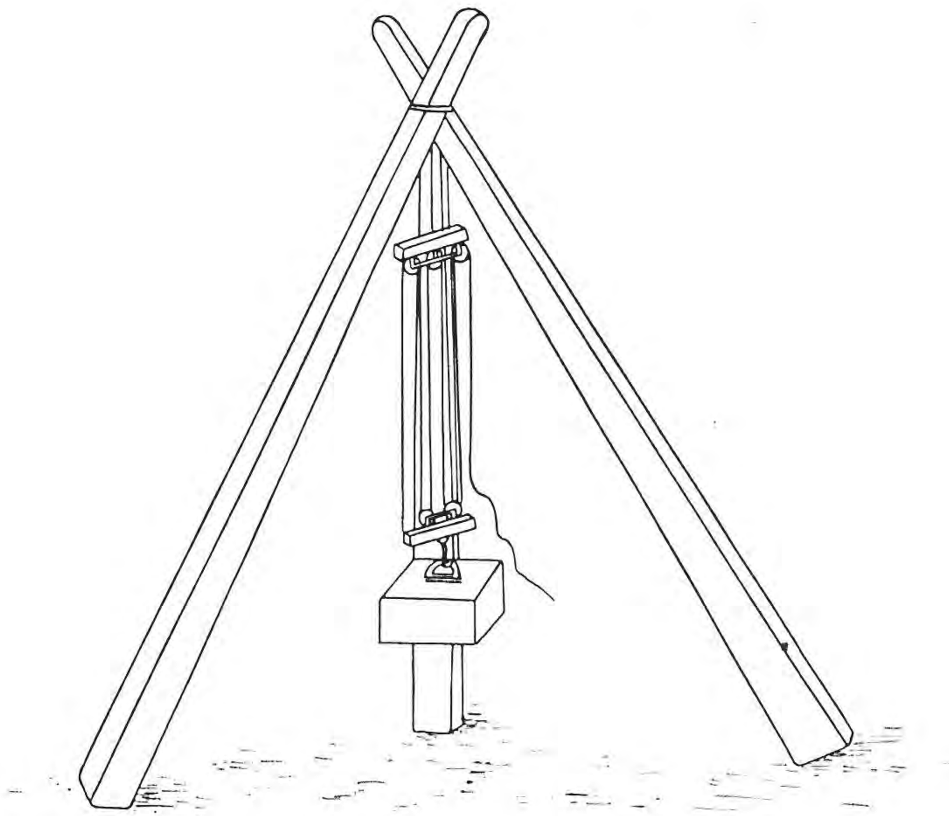

Fig.58. Triple hoist, (Martin)

6. METALS

a) Connectors

- Nails
- Cramps or double-te, (Fig. 62)
- Dowels of column drums (Fig. 38)

b) Reinforcements

- Foundations, (Fig. 63)
- Beams, (Fig. 64)

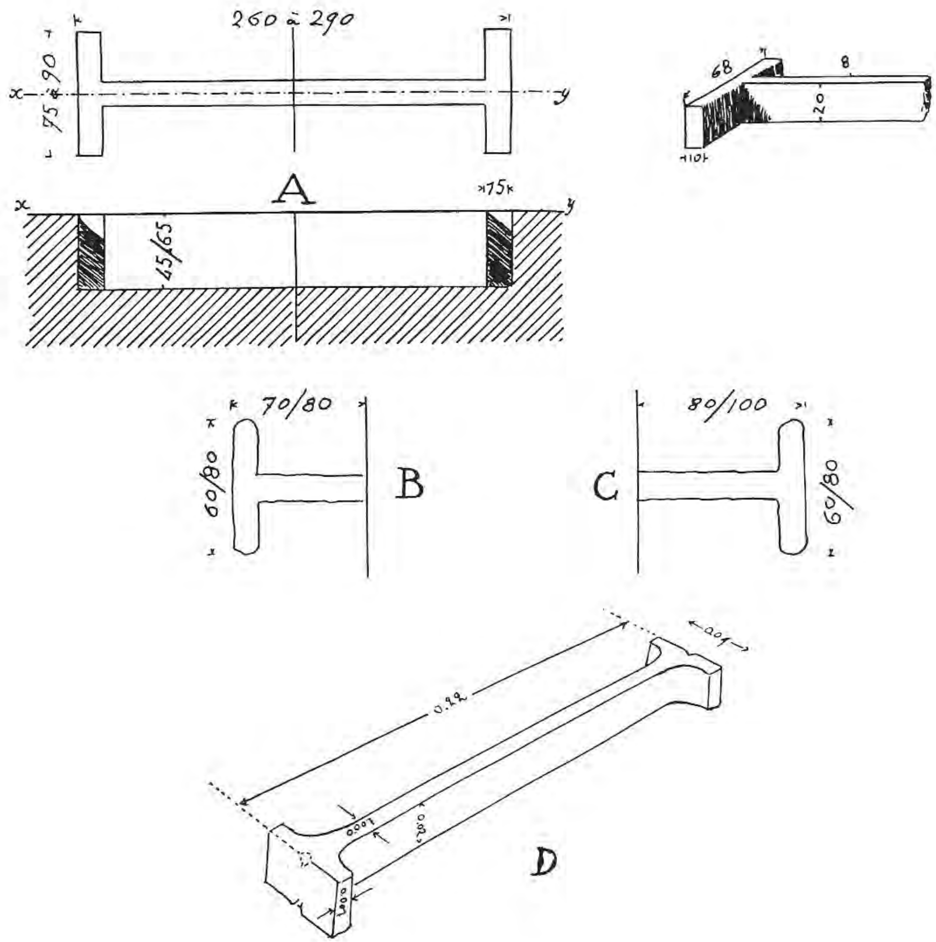

Fig.62. Double “T” metal connectors, Dēlos and Delphi, (Martin)

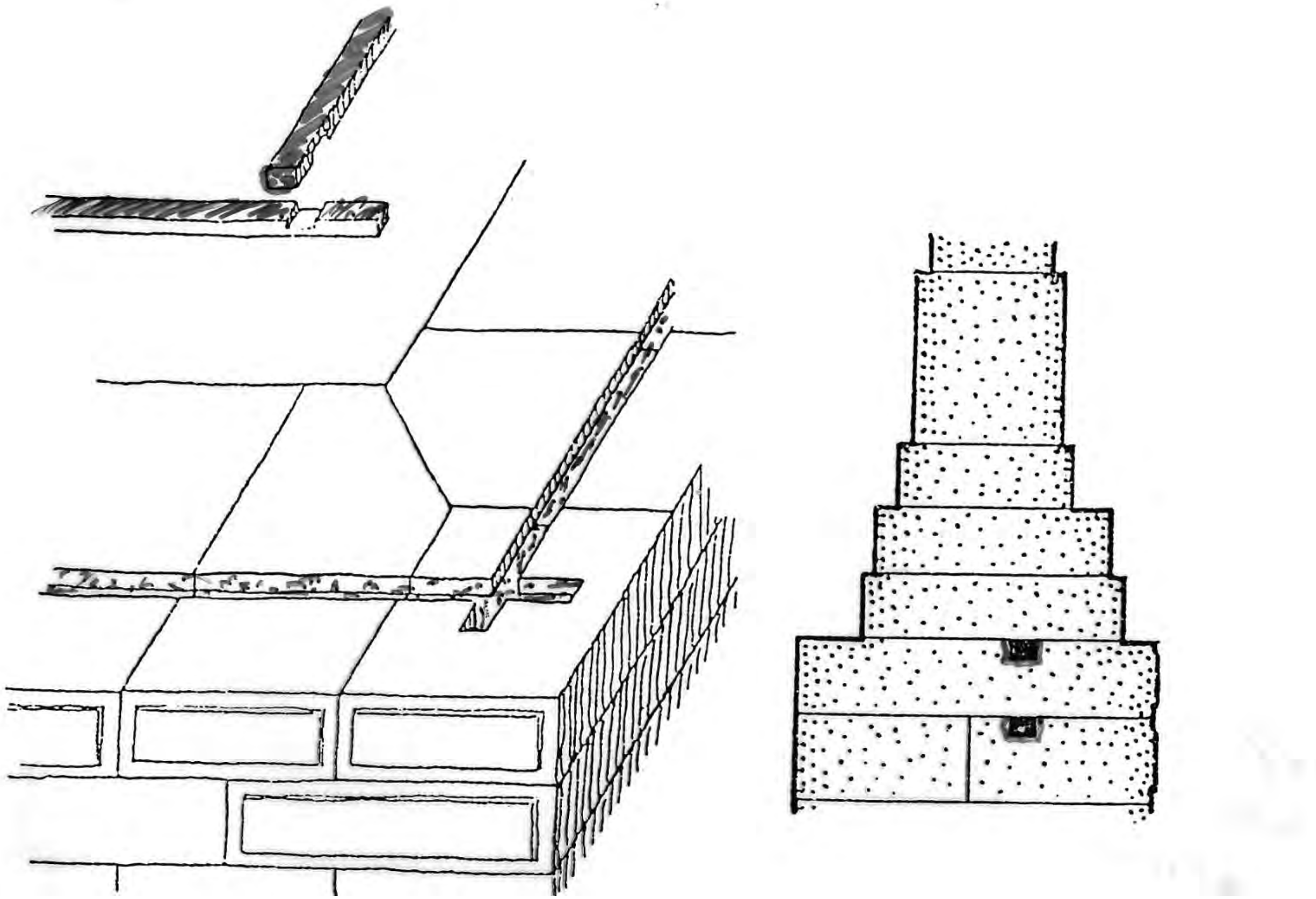

Fig.63. Iron bars reinforcing foundation beams, Delphi, Thēbeans Treasure, (Dinsmoor, in [5])

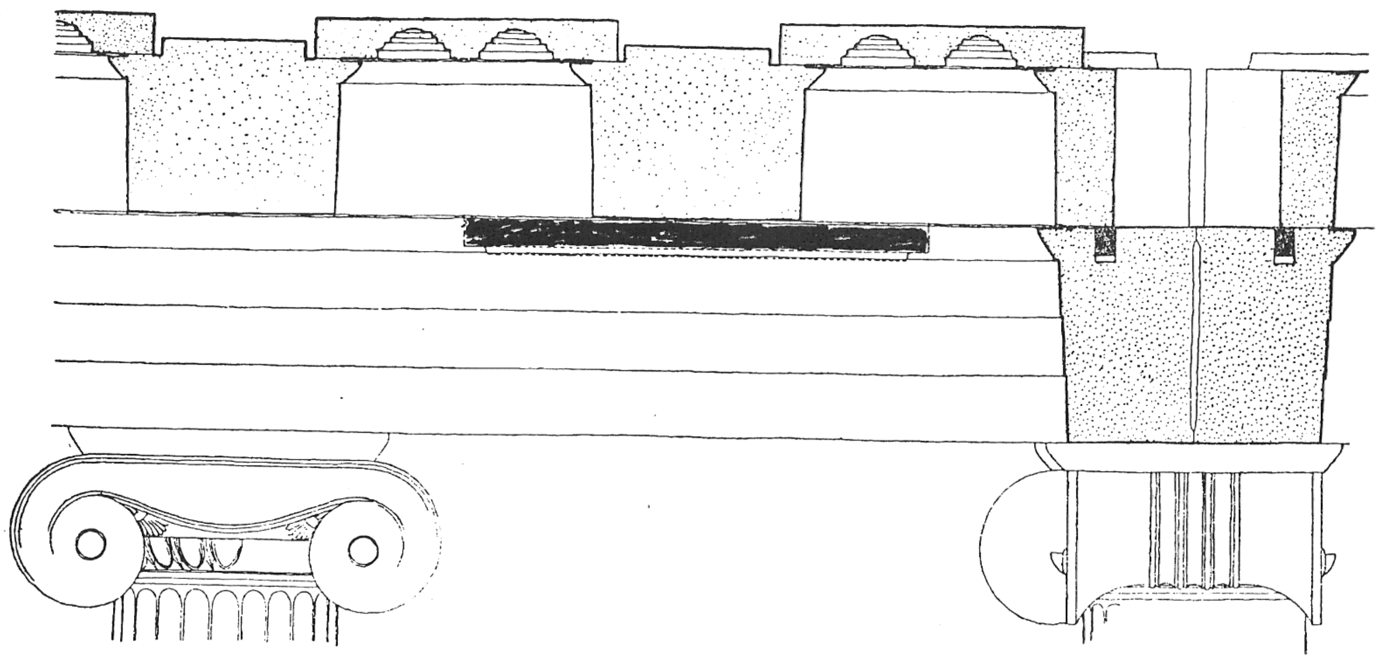

Fig.64. Iron bars reinforcing the epistyles of the Propylaea of the Acropolis of Athens, (Orlandos)

II. BRIDGES by GREEK ENGINEERS

1. **Mycēnean** period (~ 13th c. BCE)

Small span stone-bridges

- Lykotroupi, (Fig. 1)
- Kazarma, (Fig. 2)
- Galoussi, (Fig. 3)

(Note the real “key stones” combined to the corbelling system)

Fig.3. The mycenean bridge at Galoussi; a key-stone is also observed (Bougia, σ.8, εικ.3).

2. Classical period

- Timber decks
  on masonry or timber piers
  (almost completely lost today)
- Small shallow stone-passages remain
- Pontoon bridges

Fig.5. Bridge near Artemis Temple in Vravron (middle 5th cent. BCE), (Karapa, σ.21, εικ.3).

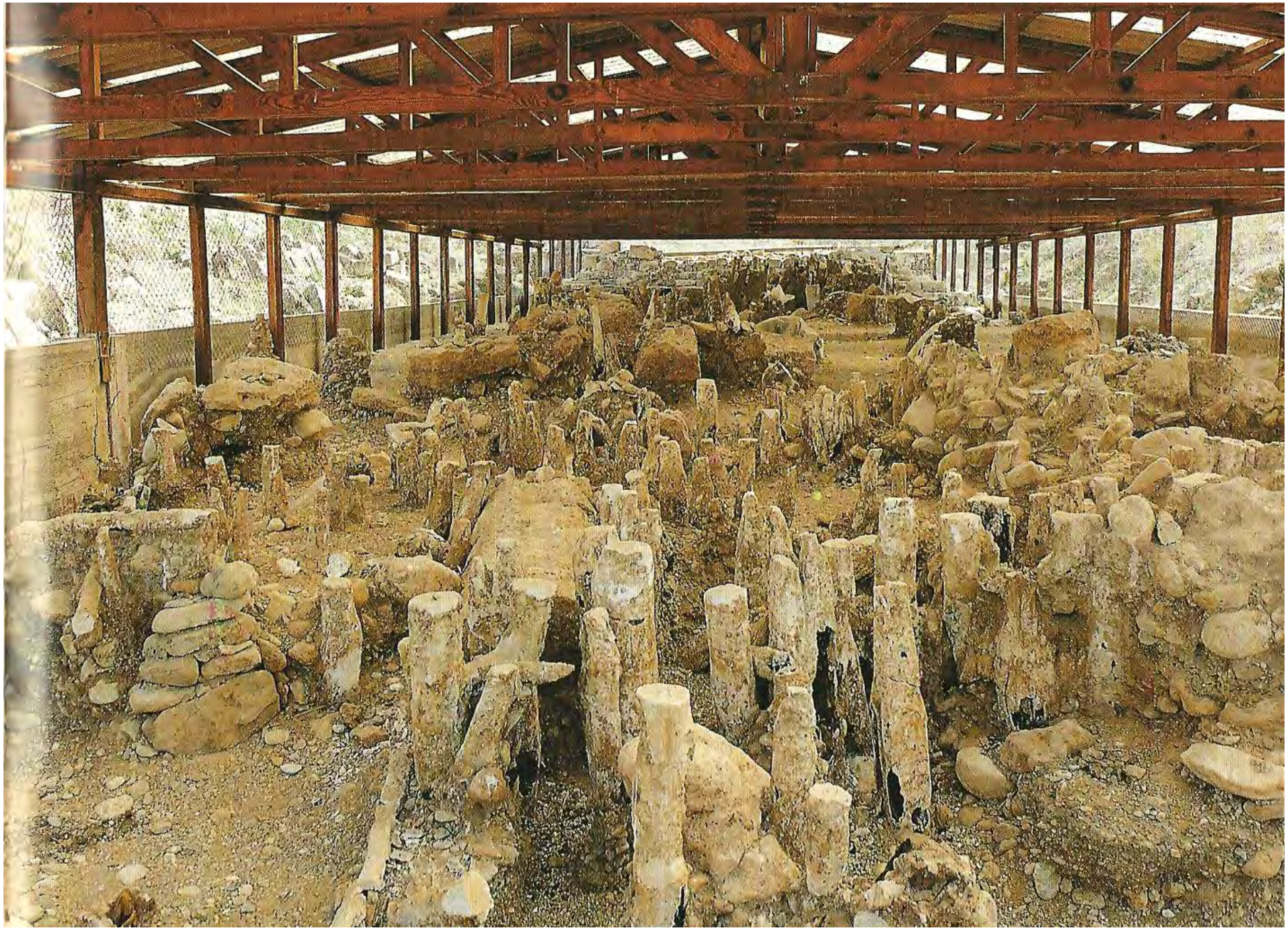

Fig.9. Close view of the timber piles of the Amphipolis bridge, (Lazarides, p.37, fig.18).

Chalkis mobile bridges (411 BCE)

– Filling-in the Euripos Straits
– Leaving a narrow navigable passage of 18 attic feet
  (Fig. 11)

- **Assos** (coastal Asia Minor)
  - piers: masonry
  - stone beams!

  4^{th} c. BCE, (Fig. 12)

- **Eleutherna** (Crete)

  (400-350 BCE)

  – Corbelling

  – Daresome 43^{o} inclination

  (Fig. 13)

Pontoon bridge at Dēlos

(Nikias, end 5th c. BCE)

- Festal procession to the island
- Avoiding debarkation in confustion
- Building a short pontoon-bridge connecting an islet to the harbour of Dēlos (Fig. 7)
- Prefabricated decks and rigs