From rigid bone plate fixation to stable dynamic osteosynthesis in mandibular and craniomaxillo-facial surgery: Historical evolution of concepts and technical developments

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TITLE PAGE

From rigid bone plate fixation to stable dynamic osteosynthesis in mandibular and craniomaxillo-facial surgery: historical evolution of concepts and technical developments.

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SUMMARY

Historically, extensive observation of limb fracture healing led to a consensus that only complete rigid immobilization could guarantee recovery. This agreement was arrived at because for a long time progress in treatment was driven by clinicians and did not stem from the application of biological research. The clinical approach was based on immobilization of the fracture by rigid osteosynthesis plates and bicortical screws. Subsequently, after extrapolation of the ideas of Lane, the concept of rigid compressive osteosynthesis rapidly gained in acceptance. It was not until the second half of the 20th century that maxillofacial surgeons concluded that the principles of osteosynthesis should be based on biomechanical studies and not only on clinical observation. The concept of stable dynamic osteosynthesis stems from basic research. This paper traces the evolution of concepts in maxillofacial osteosynthesis.

KEYWORDS: fracture healing; mandible; rigid fixation; biomechanics; static osteosynthesis; dynamic osteosynthesis.

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Introduction

During the second half of the 20th century major technological advances were made in France in the treatment of maxillofacial fractures. The Hamburg surgeon Carl Hansmann (1852-1917) was the first to experiment the plate and screw system, in 1886. He was also the first advocate of rigid plate fixation in maxillofacial surgery, which until then had only been used for fractures of the extremities. Simultaneously, the Scottish William Arbuthnot Lane (1856-1943), in a publication of 1894 [1], and the Belgian Albin Lambotte (1866-1955) [2] pioneered internal fixation of displaced fractures. At the same time, Joseph Lister (1827-1912), the British surgeon and medical scientist, laid the foundations of antiseptic medicine [3]. However, because of the high rate of complications such as infection and facial nerve lesions osteosynthesis of mandible fractures was for many years put on hold. Almost a century later new concepts and progress in technical developments enabled oral and maxillofacial surgeons to advance from rigid bone plate fixation to stable dynamic osteosynthesis.

The aim of this presentation is to clarify which terms should be used for each of the different techniques of fracture treatment and to outline the principles which first led to the fixation techniques for mandible trauma.

1. Terminology

When discussing osteosynthesis it is of paramount importance to use uniform terminology. For logical reasons, the name of a surgery technique should depend on its nature and results and not on the name, form or features of the material used. According to this principle, osteosynthesis can be rigid or dynamic and the result can be described as stable, unstable or

solid. The term used should reflect the reality of the situation. This is why we propose the following definitions.

A fixation is said to be “unstable” when it needs to be completed by an intermaxillary fixation (IMF), which historically was the case of osteosynthesis with steel wire. This approach had the drawback of periosteal stripping of both sides of the mandible [2] with impairment of the main blood supply to the bone [4]. An unstable fixation is a failure.

In contrast, osteosynthesis is deemed to be “stable” when the broken limb can, before the fracture heals, be moved freely without application of force. For the mandible this means that the fixation does not require any associated IMF and that passive movements are possible and do not prevent the healing process. The fixation is stable at rest and during effortless movements. Liquid food is authorized [5]. Preferably, only very light masticatory pressure should be applied.

The term “solid” refers to osteosynthesis that allows full operation of the mandible, including mastication, whether or not bone healing is complete. Most of the time, osteosynthesis is solid only when bone healing is complete.

The term “functionally stable” does not make a clear distinction between a stable and a solid fixation: both are functional but only one is solid.

The term “rigid” indicates that the plate absorbs any force applied on the operated mandible. The plate can withstand all efforts exerted by the masticatory muscles without suffering any deformation. This term is sometimes used not only to designate the plate but also osteosynthesis itself or, in other words, the result of the process. Depending on the force applied a plate is qualified as either rigid, elastic or flexible. In contrast, synthesis can only be stable, solid or unstable. Mechanically speaking, the term “semi-rigid” does not make any sense.

2. Evolution of the concepts from orthopedic surgery to treatment of facial fractures

At the end of the 19th century, the possibilities offered by surgical treatment of fractures drew the attention of oral and maxillofacial surgeons [6]. Lambotte coined the term osteosynthesis and established the ground rules for the technique: maintaining the bone's blood circulation, limiting dissection, and preserving the periosteal covering [2]. He used a trapezoidal metallic resorbable plate made of nickel silver, a copper alloy with nickel and often zinc. His work had a considerable impact on orthopedic surgery but not on craniofacial surgery. The risk of lesions of the facial nerve during the cervical incision, the difficulty in restoring the dental occlusion owing to the rigidity of the plates, the risk of lesions of the alveolar nerve, the damage inflicted upon the tooth roots by the bicortical fixation of the screws and the high infection rate before the discovery of antibiotics impeded progress. Bradley *et al.* [7] stated that in the tooth portion, a fracture is a compound fracture directly communicating with the mouth cavity. They emphasized the importance of adapting and fully immobilizing the fractured surfaces (a mandatory requirement for recovery of the dental occlusion) and recommended that all teeth should be removed from the line of fracture to avoid chronic suppurative osteomyelitis. Since then, the treatment of fractures, malformations, cancers and bone fragment loss due to cancer or infection has become safer as control of the biological and mechanical factors that ensure better fixation and biologic healing has improved.

3. From clinical observation to empirical therapeutic applications

3.1. From bicortical to monocortical osteosynthesis

The first theories stated that the injured limb bone should be completely immobilized by rigid plates. The technique was first experimented in 1895 when Lane [8] developed a metal plate to be used for internal fixation. Many authors, such as Aubry and Ginestet, advocated this

technique in the treatment of fractures of the mandible [9,10,11]. The approach is based on the idea that physiological bone healing is only possible when rigid fixation of the fracture is performed. It is accepted that bone healing is characterized by the absence of periosteal callus formation, called *soudure per primam* (primary bone healing). According to Müller and Perren, the appearance of any periosteal callus after plate fixation can be an indicator of an unknown degree of instability and infection [12].

In line with these precepts**,** Danis developed numerous techniques of osteosynthesis based principally on interfragmentary compression using screws and a device that he called "coapteur", which was basically a plate designed to produce axial compression between two main bone fragments [13]. His model was extrapolated by Luhr [14] and Spiessl [15] to the management of mandibular fractures: stability was enhanced by increasing the friction forces between fracture surfaces and using specific rigid plates with bicortical screws specially designed to provide inter-fragmentary compression. This method consists in stable internal fixation of fractures by an eccentric dynamic compression plate (EDCP).

In 1967, Franchebois and Souyris started using modified Müller plates, a design that allows inter-fragmentary compression in the treatment of fractures of the mandible by tightening a tensor temporarily anchored to the bone and the plate [16,17]. In this approach, the plates are fixed to the inferior border of the mandible. As a result of stable internal fixation, intermaxillary fixation was no longer necessary. The technique allowed free mobility of the mandible and a soft or semi-solid diet. Initially, it was restricted to subjects contraindicated to IMF such as epileptics and edentulous patients and in cases of pseudoarthrosis and plurifocal fractures.

Thus, although intermaxillary fixation was no longer a requirement, new challenges emerged: the difficulty to concomitantly control dental occlusion and fracture reduction, and avoid disjunction of the alveolar rim at the fracture angles.

To counter the problem, Michelet along with Franchebois and Souyris developed the intra-oral approach [16,18,19]. The method avoids skin scars, facial nerve damage, restores occlusion, allows traumatized teeth to be treated and direct observation of the alveolar bone. As a result of the endo buccal incision, the plates could not be placed at the inferior border of the mandible, and because of the position of the tooth roots bicortical screws could no longer be used. Souyris and Michelet suggested placing the plates on the upper border of the mandible

using monocortical screws to avoid alveolar rim disjunction and systematic tooth lesions while respecting the principle of rigid fixation [17,18].

3.2. From the principle of rigid compression fixation to stable dynamic osteosynthesis

As in skin surgery, compression of a biological tissue damages its blood supply. Sustained compression on the fracture surfaces can suppress or at least reduce the blood supply. For these reasons, continuous compression seems illogical and inappropriate. Enhancing or disturbing bone healing in the area adjacent to the fracture surfaces depends on how much compression is exerted on the fracture surfaces, under the plate and around the screws. The so-called “dynamic compression” of Luhr and Spiessl was in fact a single mechanical compression while the term “dynamic” implied several repeated micro-movements caused by muscular activity. Although Luhr’s plate was called a dynamic compression plate (DCP) only one-time static compression could be obtained. This stage in the development was still empirical and based on clinical observations.

In 1870, Wolff is credited with originating the trajectory relating bone structure to the mechanical forces imposed upon it: where stresses of pressure and tension occur in bone, formation of bone takes place [20]. A hundred years later, McKibbins (1978) advanced the

principle of “secondary fracture healing” [21]. This process is possible when complete rigidity is not achieved, which results in greater motion at the fracture site and a degree of intermittent displacement between the bone ends. Healing progresses via the three-stage process of inflammation, callus formation and remodeling. The goal of this complex process is a stepwise increase in the mechanical stability of the fracture site that is achieved by progressively replacing fragile provisional tissues with more stable ones, eventually reaching a point that allows vascular ingrowth and mineralization processes to occur. Finally, the procedure of stable dynamic osteosynthesis was adopted and the technique of rigid fixation was abandoned, thereby introducing a new rationale in the treatment of fractures.

3.3.The concept influences the design of the plate and not vice versa

Many publications have focused on the study of plates, their form, dimension, nature and tolerance [6]. Defining the concepts underlining the treatment methods is more important than stating the nature or dimensions of the material used. Maxillofacial plates and screws are smaller than the material used for limb surgery. Thus, once the concept of stable-dynamic osteosynthesis was adopted, the first publications used the term miniplate osteosynthesis as opposed to material used for limb fractures. The use of the term miniplate quickly became widespread and was soon universally accepted [18]. To date osteosynthesis of mandible fractures has been qualified by the material used and not by the technique. Adaptive osteosynthesis, which means restoring the morphology of the fracture by precisely adapting its surfaces would have been a more appropriate term.

The term “miniplate osteosynthesis” led to problems when Michelet began to work with resorbing plates [22, 23]. The procedure still corresponded to adaptive osteosynthesis but the term “miniplates” was a misnomer because of the dimensions of the resorbable plates [19].

4. From experimental studies to stable dynamic osteosynthesis.

During a period that could be called the empirical stage the methods used were a direct application of contemporary knowledge of general orthopedic surgery to the mandible.

There then followed a period in which the compression principle was extrapolated to mandibular surgery and the techniques used followed or preceded knowledge of the bone healing process [13,24]. New developments in this third stage, the experimental period, arose mainly from biomechanical studies undertaken in Strasbourg from 1972 to 1974 by the Groupe d' Etude en Biomécanique Ostéo-Articulaire de Strasbourg (GEBOAS), who not only created a new concept but also described the features of the plates and screws to be used for the method [2,8,13,24,25]. The GEBOAS performed static and dynamic experiments to establish objective principles in mandibular osteosynthesis.

4.1.The cortical bone

In the late 1970s, studies described the external surface of the mandible, calculated the distance between each dental root tip and external surface of the outer cortical layer of the mandible and to the inferior border of the mandible and clarified the position of dental root tips in relation to the occlusal line and the inferior alveolar nerve. The observations showed that the cortical bone of the mandible had an average thickness of 3.3 mm and that the basilar area is thicker and the apical alveolar area considerably thinner [5] .

4.2. Clenching forces

The GEBOAS measured the breaking load of an isolated mandible with an Adamel Lhomargy machine and were then able to determine the resistive forces of the plates and the bite force**.** The value obtained helps to determine the mechanical resistance of the plates. Torsional moment, or torque, was also analyzed in the curved symphyseal region [5] (Fig.1).

4.3.The localization of plates and screws on a fractured straight beam

Once the clenching forces had been measured, it was necessary to determine the distribution of the strains developed inside the mandible. When pressure is applied on the free end of a straight unilaterally fixed beam, traction strains are recorded on the upper border and compression strains are visible on the lower border. However, at the point of force application, forces are shifted. When a load is placed on the extremity of the fractured straight beam, if the fracture is fixed in the lower border of the beam, compression and traction strains are recorded on the lower border and diastasis occurs at the upper end of the fracture line. If the plate is located along the upper border of the beam, traction strains are neutralized. Compression strains remain concentrated at the lower border. No disjunction occurs (Fig.2). When a force is directly applied to the upper extremity of the fracture line, compression strains are observed at the point of application of the force and traction strains at the lower border, the opposite of what is observed when the force is applied at a distance [5,26]. This neutralizes traction stresses and reestablishes the normal run of concomitant compression stresses. The later works of Farmand reported that the direction of torsion and traction forces was reversed at the impact point of a clenching force. Subsequently, studies of a curve beam subjected to a load showed that torsion strains could be neutralized by two plates [27]. Thus, a fracture of the mandible behind the canine can be fixed with a single plate whereas a fracture of the symphysis requires two plates to neutralize the torsion forces exerted in the curved area (Fig.3) [28].

4.4. Periosteal bone healing

Other investigations were performed to determine whether the upper position of the plates is transferable to the mandible, which is a curved model. A study carried out under the supervision of M. Grossman of the Laboratoire de spectroscopie et de photonique iconique de l'Institut de Physique (Pharok Piam) [29] used a laser beam to examine recently collected post-mortem fractured and synthesized mandibles. Two cameras were placed in a rigid position and centered on the fracture line of the mandible. One camera was lit by a laser flash light with the image obtained serving as a reference. The osteosynthetized mandible was then subjected either to traction strains or to torsion strains. Further photographs were taken and merged with the reference images to measure with greater accuracy the interference fringe caused by superimposition. These results showed micro-movements between the osteosynthetized fragments, which was contrary to the expected result of strict immobilization principles that had been recommended until then. They also demonstrated that in no case could the new mode of fixation be considered as rigid. These observations confirmed that mechanical stimulations spread from one fragment to another help the healing process by recreating conditions similar to bone physiology [30,31].

A case series involving two patients suffering from a mandibular fracture secured with a plate included direct examination of their stabilized fractures.

On the 10th day, surgical exposure of the fracture site showed that the periosteum had completely covered the fracture line, screws and plates. The periosteum had thickened and showed no signs of inflammation. Light and careful pressure on the dental crown, at the top of the fracture line, showed slight, fleeting diastasis of the inferior border of the mandible.

This direct observation of the surgical site demonstrated that bone healing was of a periosteal nature and not primary bone healing. It also confirmed that the different strain forces were reversed at the impact point of a masticatory force applied to the fracture line. Stable dynamic

fixation of a mandibular fracture allows recovery of the physiological condition of the bone [5].

4.5.The ideal plates and screws for stable dynamic osteosynthesis

Once the location of the plates and screws has been established, resistance of the external cortical bones to the pull-out forces applied on the screws can be assessed. The choice of osteosynthesis material should be compatible with the specific biological and mechanical imperatives of the mandible: tolerance, solidity and ductility. GEBOAS used a modified Young's modulus to achieve the proper rigidity and flexibility of the metal. The rigidity, elastic limits and breaking point of material under loading were then measured. Bendable stainless steel was the first suitable material to be used but was progressively replaced by titanium. The shape of the plate (thickness of 1.00 mm, length varying from 4 holes with or without a bar) and accommodation of the screw holes were influenced by the design of Shermann et al. The characteristics of the screws depend on the thickness and structure of the cortical bone. Different materials have been used to manufacture the plates and screws. Hansmann used gold and Lamotte nickel silver (resorbable). Later came steel, stainless steel, titanium and finally resorbable Phusiline plates and resorb plates, developed by Champy and Gerlach, respectively [19,23,32]. Michel et al. started using Phusiline, which is perfectly tolerated, in 1971 but later abandoned the technique [33, 34].

CONCLUSION

For a long time the aims of surgical treatment of the fractures of the jaw using plates and screws were always the same: restore the occlusion and ensure bone healing. The historical evolution of the principles of treatment and the technical developments of the treatment methods occurred in three stages. The first stage, which should be called adaptive

osteosynthesis, consisted in strict immobilization of the fracture with rigid plates and a bicortical fixation. The surgical approach was extra-oral with a high risk of damaging teeth roots, facial nerves and the inferior alveolar nerve. Restoring the occlusion was problematic. The second stage, rigid compression osteosynthesis, required the development of special rigid compressive plates derived from the coapteur of Danis. The method consisted in increasing stability by increasing compression and friction forces. Restoration of the occlusion was not easy and damage to the inferior alveolar nerve was frequent. Bone healing was of the primary healing type. The third stage, stable dynamic osteosynthesis, consisted in the restoration of the lines of force in the mandible and the transfer of micro-movements between the two fragments. The material used is adaptable, which results in easy protection of the nerves and teeth and restoration of the occlusion

The biomechanical study performed by the Strasbourg bone and joint research group (GEBORS) showed that fixation of a bone structure had to be performed with a technique that neutralized the traction and rotation forces and restored the compression and friction forces.

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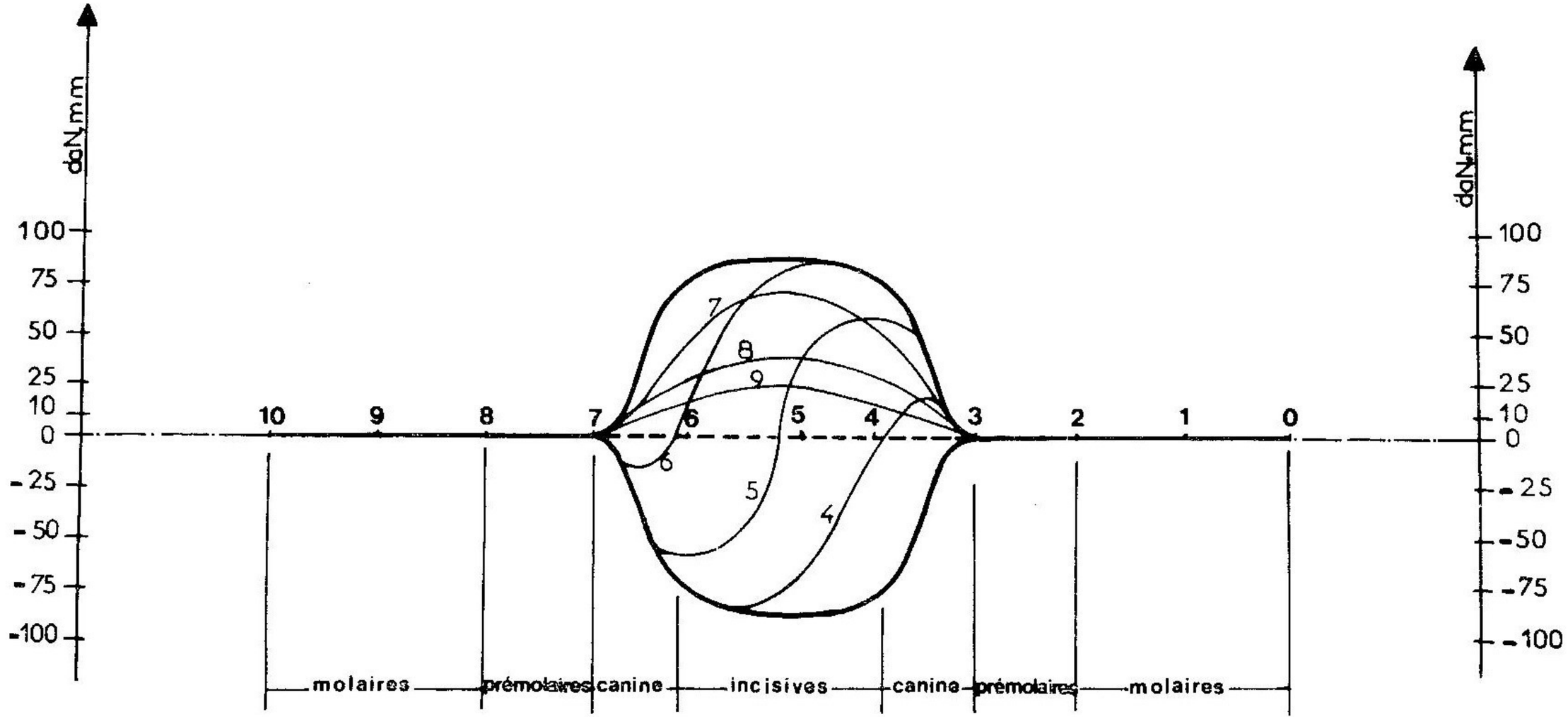
CAPTATION TO ILLUSTRATIONS

Figure 1: Torsion moments in the symphysal region

Figure 2: Photo-elastic stress analysis of an acrylic bar

Figure 3: Ideal line of osteosynthesis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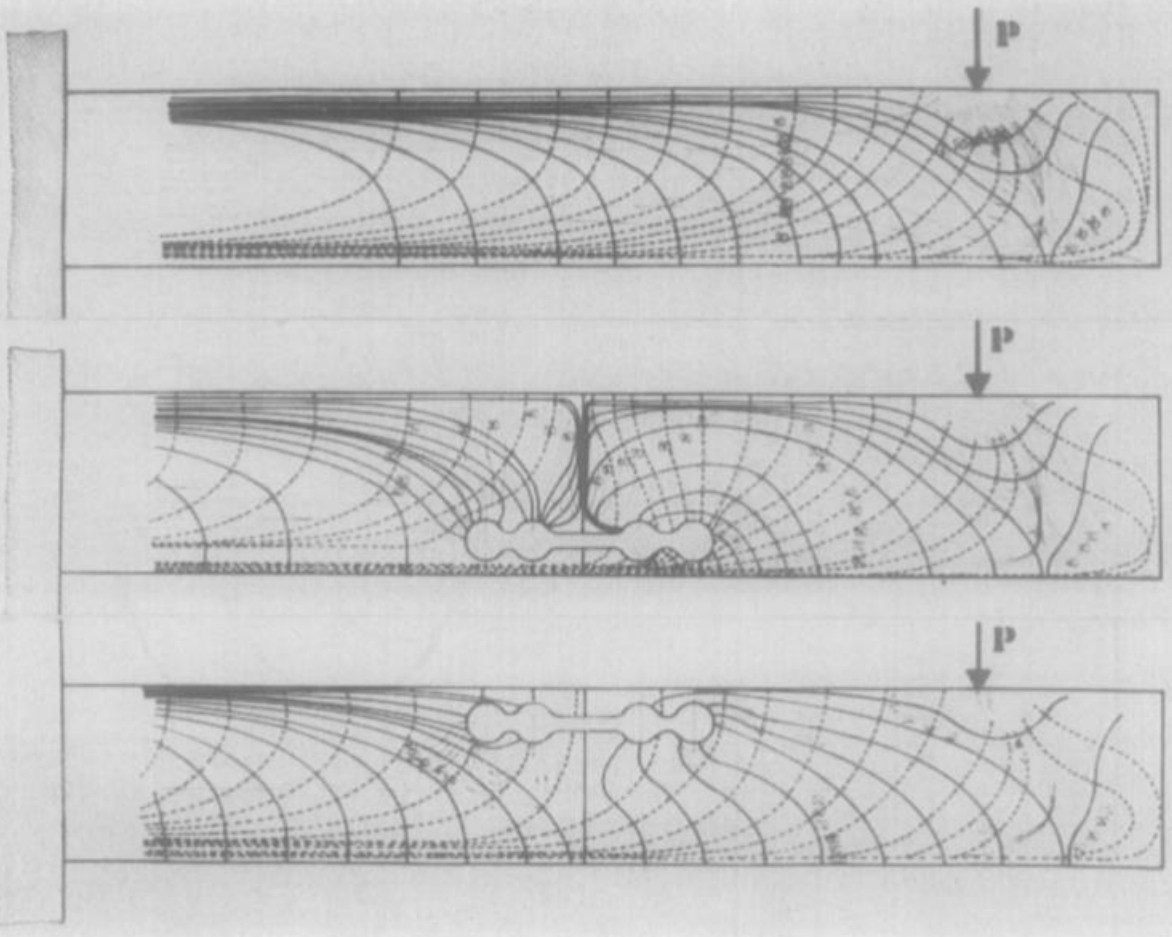
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