STUDY AND RECOMMENDATIONS ON THE SAN GERMAN VAULTED BRICK TUNNEL STORM SEWER SYSTEM

by Luis Pumarada-O'Neill
Department of General Engineering

and

Miguel Cruz-Arocho
Department of General Engineering

Project No. 5

Grant Agreement No. 14-08-0001-G-1446

FINAL TECHNICAL REPORT
TO
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D.C. 20240

"The work on which this report is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Research and Development Act of (P.L. 98-242)".

July 1988

ABSTRACT

The storm water drainage of a 0.51 km2 basin within the hilly city of San Germán, Puerto Rico, goes through a system of vaulted brick tunnels covering former surface streams. The subject of this work is its main tunnel, 842.53 meters long, which belons to a stream called Quebrada Manzanares.

This stream channel was enclosed segment by segment, haphazardly, between c.1835 and c.1915. The first documented vaulting was a c.1835 road arch bridge. It was followed by street culverts and by tunnel segments erected by landowners who wanted to build structures on properties crossed by the stream. Because of this fact and the variations in width and depth of the meandering channel, the tunnel direction, its construction techniques and cross-sectional dimensions vary significantly along its interesting length.

Parts of this system threaten to collapse because of vault cracks and undermining by water which leaks out through damaged tunnel floors.

The great tourism potential of the Quebrada Manzanares tunnel is affected by several factors, principally: flash floods during storm events, and polluted water due to illegal discharges of raw sewage.

Our most urgent recommendations concerning the main tunnel are: open a service access, repair its damaged floors, stabilize its vault and remove the raw sewage discharges.

ACKNOWLEDGEMENTS

We are very grateful to the following persons for their help and contributions to this project: Edwin Albino-Pluges, local historian, who did the historical research at the San Germán Historical Archives; Rafael Cabrera, graduate student, who did the same at the Puerto Rico General Archives an San Juan; surveying students Angel Noel Colón-Guzmán, who participated in the underground and surface surveys, and Rafael Torres-Lopategui, who also worked in the surveys and produced the first version of the drawings; engineering students Sandra Acosta and Carlitos Lozada, who worked on drawings and figures, and Roberto Barbosa, who helped to determine the drainage basin and estimated its area; geologist Joseph Troester, who provided advice on dye tracings; spelunker Thalia Veve, head of the Cave Surveying Committee of the Sociedad Espeleológica de Puerto Rico, Inc., who trained us in underground compass and tape surveys; fellow faculty member Roque Román, who assisted in the water samplings; and Roberto and José Cruz, who provided surface support and safety from flash floods during the underground survey and photo sessions.

We also want to thank the directors and personnel of the Engineering Research Center and the Water Resources Research Center: Dr. Rafael Munoz-Candelario and Dr. Luis del Valle, for their guidance, cooperation and ideas, Victor Ramirez, who produced the final version of the drawings, Onil González, who did the delicate reductions and copying, and Sara and Aida Feliciano, who took care of the paperwork and typed our manuscript with unexpected promptness.

We have special thanks for Domingo Jusino and his employees at La Cueva de Luis Candelas Discotheque, who permitted us full use of its tunnel entrance, and for the invaluable help of Angel Luis Torres Vázquez, who climbed and crawled to investigate the origins of high drains and tight branches.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This project studies a striking 19th Century storm sewer system consisting mostly of vaulted brick tunnels which is still in use beneath downtown San Germán. Its main tunnel runs under buildings and crosses under city streets; it discharges into a stream channel going into the Guanajibo River.

The project intends to evaluate the tunnels' performance as a drainage system and to make recommendations pertaining their future impact on the development of the tourism-oriented city of San Germán.

The San Germán city government, which owns and mantains all city storm sewers, considers opening part of the 842.53 meter long main tunnel to visitors as a tourism attraction. However, the permanent waterflow, the danger of flooding, the foul smell and pollution due to the presence of fecal matter prevent its use as a tourism attraction.

A highway projected across the drainage basin may modify the basin and hence its flow volume. The amount of runoff carried by the tunnel system could also be affected by the potential re-development of the Ancones district, a sector which has a large percentage of substandard housing, and by the possible develoment of several acres which are presently forested and belong to the Antongiorgi family.

Many parts of the vaulted brick system are over 100 years old, and have not received maintenance for decades. Several years ago, a part of the system under Calle Alfonso XII collapsed, and as a result the street had to be closed to traffic for several months while costly repairs were completed.

This project addresses the following objectives:

1. Determine the date and manner in which these tunnels were built and their original purpose. Document subsequent additions and modifications.
2. Draw the tunnel system and establish its relationship to existing buildings and streets.
3. Determine the drainage area served by the system.
4. Recommend ways to make the main tunnel into a tourism attraction.
5. Establish the present conditions of the tunnels in relation to their structural stability and their internal surface drainage conditions.

Different objectives are met by different sections within this report. The methodologies used are specified within the corresponding section.

The route and size of the tunnel and its position relative to buildings and streets are described in the section "Detailed Description" and in the drawings and photographs. These sections also establish the tunnels' tourism potential, as well as the pollution and threats of collapse which are evident.

The sections "Historical Background" and "Detailed Description" provide historical data. The first one presents a chronological account, while the second discusses the different tunnel segments taken in a downstream direction. "The Historical

Background" section includes conclusions on important historical and documentation questions.

The "Drainage Basin" segment presents basin boundaries and estimates storm-flow volumes.

The "Water Quality" segment quantifies the pollution present in the system.

The "Structural Integrity" segment identifies evident threats of collapse and of deterioration.

The "Tourism Development" section discusses the tourism potential of different parts of the tunnel, and ways in which to deal with obstacles to development.

The report ends with recommendations on how to deal with the immediate problems: threats of collapse and pollution by raw sewage. It specifies alternatives for improving the system's service and for tourism development.

The references cited include primary and secondary sources as well as the names of persons interviewed who provided useful information.

The appendixes include drawings of the main tunnel (based on a compass and tape survey), and photographs of some typical and particular features.

GENERAL PHYSICAL CHARACTERISTICS

The main part of the San Germán vaulted brick tunnel storm sewer system, the subject of this project, covers the underground course of Quebrada Manzanares from its headwaters to its resurgence as a surface stream, 842.53 meters away, measured along the stream-bed. The general course of this tunnel is shown on the Site Plan (See Drawings, Sheet No. 1).

The main tunnel resulted from the haphazard covering of Quebrada Manzanares by individual property owners and street culverts between c.1835 and c.1918, as its banks became urbanized (See "Historical Background").

The typical section of the main tunnel has rubble-mansory walls, a concrete floor with a gentle slope to its center and a barrel-vault either recessed or flush with the walls, which is 1/2, 1 1/2 or 2 bricks thick (See Photo No. 15 and Figure No. 1). Widths of the main tunnel range from 36 inches to 148 inches, and heights from 38 inches to 117 inches.

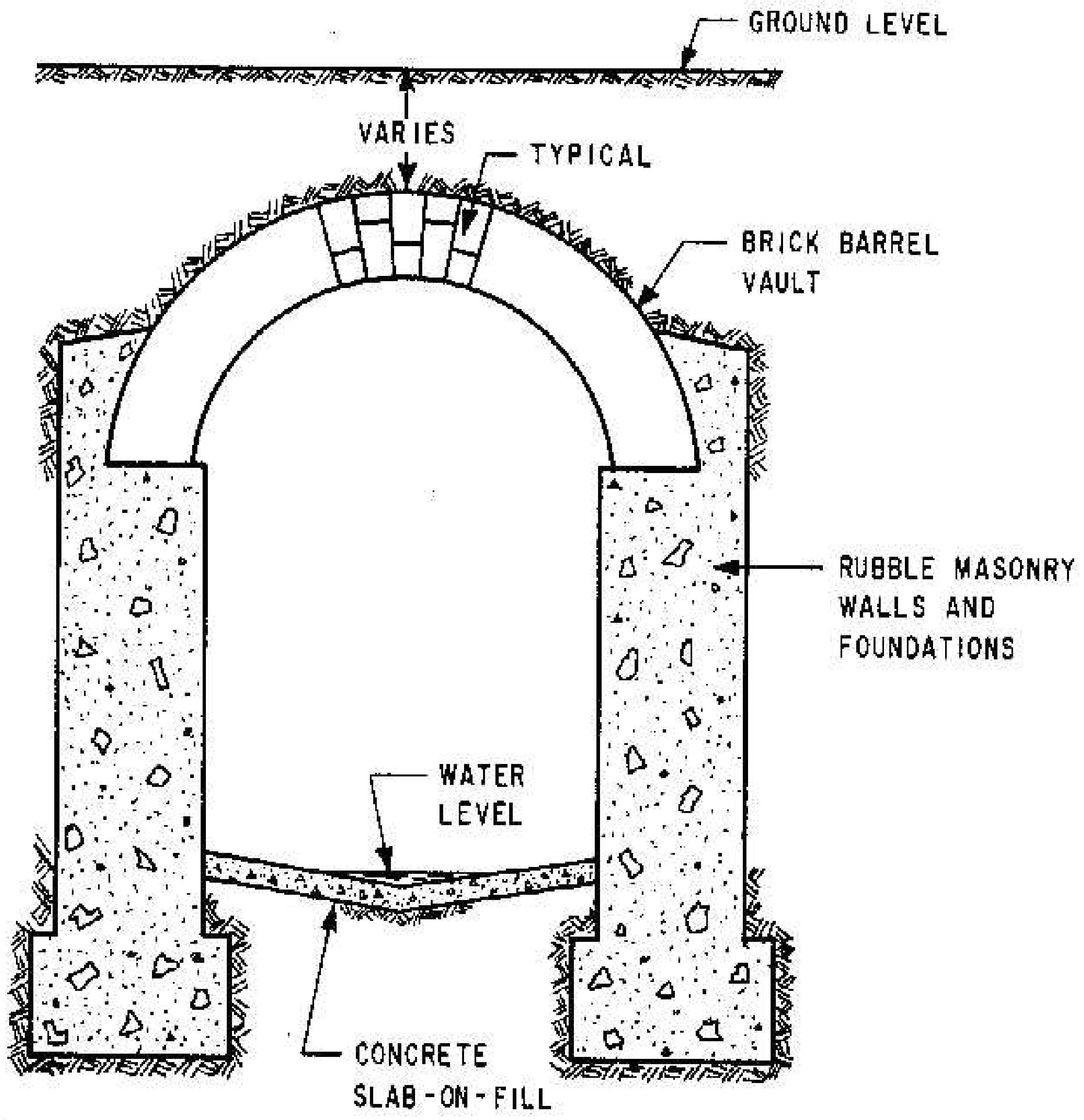
The maximum dimensions do not occur at or near the point of discharge, but at isolated intermediate points. In general, tunnel sections originally built as street culverts and bridges are higher and wider than tunnel sections located beneath city blocks. This is due to the fact that while the roadbeds are raised above grade, building foundations, basements and sunken yards reach several feet below grade.

Drainage structures built to conduct storm water into Quebrada Manzanares were being built as early as the 1860's (See "Historical Background"). Quebrada Manzanares receives storm

2 BRICKS THICK

1/2 BRICK THICK

PARTIAL VAULT SECTIONS



SECTION OF TYPICAL 1 1/2 BRICK THICK RECESSED TUNNEL SEGMENT VAULT

FIGURE 1
"TYPICAL STRUCTURAL TUNNEL SECTIONS"

waters from roofs, yards, parking lots and streets through drains, pipes and through relatively small vaulted brick branches (See Photos Nos. 9, 10 and 11) at dozens of points along its underground course (See Drawings).

The vaulted brick branches, most of them abandoned and sealed, date mostly from before 1910. A good number of these vaulted branches were probably for conveying raw sewage from properties less than three blocks away before the sanitary sewer was built in San Germán around 1935 (See "Historical Background"); a few of them still do (See Drawings and "Water Quality").

Quebrada Manzanares is still joined at a few points by other permanent streams flowing through smaller vaulted tunnels or pipes (See Drawings and "Historical Background").

GENERAL ROUTE OF THE MAIN TUNNEL:

The upper part of the Quebrada Manzanares tunnel follows a generally northerly direction down the slope of Ancones Mountain, keeping generally parallel to Calle Esperanza, which it crosses about halfway down. This part of the tunnel averages 38 inches wide and 44 inches high near the top, 48 inches wide and 64 inches high just south of Calle Luna, and 48 inches high and 63 inches wide below this same street.

After a sharp turn, Quebrada Manzanares runs generally east along the bottom of a valley, nearly parallel and to the north of Calle Luna. This gently-sloping second part of the tunnel varies frequently and sometimes sharply in cross-section: it is 148 inches wide and 117 high just west of Calle Cruz; 73 inches wide and 40 inches high east of Calle Ramas.

Past the eastern slope of the hill crowned by Porta Coeli Chapel, the Quebrada Manzanares valley joins the Guanajibo River valley, and the tunnel again turns north. This third part of the tunnel is rather recent, it consists of a gently sloping rectangular concrete culvert, 63 inches wide and ranging in height from 81 inches under Calle Javilla to about 50 inches at the outlet. The culvert's roof slab serves as a sidewalk for Calle Vivoni and, farther on, as a narrow access road to properties located north of the Vivoni housing development. From the end of this culvert on, Quebrada Manzanares continues as a surface stream, joining the Guanajibo River about 200 meters north of the mouth of the tunnel.

HISTORICAL BACKGROUND

HISTORICAL AND GEOGRAPHICAL DATA ON THE CITY OF SAN GERMAN:

San Germán is one of the oldest cities in Puerto Rico. The island was originally divided by the Spanish settlers into two districts (partidos): Puerto Rico (later San Juan) on the east and San Germán on the west. The earliest western settlement dates from c.1511. Its citizens were forced to move from one site to another by repeated Indian and pirate attacks. The city occupies its present site since 1573 (Vélez-Dejardin, 1983).

The older part of San Germán sits on a foothill overlooking a bend of the Guanajibo River, a normally placid, shallow West-flowing stream which has carved a flat valley between two mountain ranges. The main range to which the San Germán foothill belongs to runs east-west, south of San Germán.

Several year-round springs flow north from this mountain range, forming streams (quebradas) which join the Guanajibo River. The mountain just behind the city is called Ancones. The springs south of the San Germán foothill flow down the north slope of this mountain, turn east until rounding the San Germán foothill, then flow north again until discharging into the river. Of these stream, the one originating farthest to the west is Quebrada Manzanares; some of the other streams merge into it. During heavy rains, stormwater flowing down the rather steep slopes join Quebrada Manzanares, augmenting its flow from trickle to torrent.

QUEBRADA MANZANARES:

Up to the mid-1800s, the era during which the urban development of San Germán first took a rapid pace, the east-west course of *Quebrada Manzanares* served as a boundary for its urban area. The lands just south of the stream belonged to the city government as common land (*égido común*); to its north there were privately-owned plots of land, most of them vacant. The road entering San Germán from the west became *Calle Luna* upon approaching the urban area, it went through the *égido común*, keeping a safe distance away from the east-west course of *Quebrada Manzanares*. The ground-plots which bordered on the north side of the stream were served on their opposite sides by *Calle Manzanares*, a narrow street only a few blocks long. (See Figure 2).

Quebrada Manzanares turned north across Crown lands (belonging to the Santo Domingo Convent--Porta Coeli Chapel, built in 1606) *enroute* to the Guanajibo River.

The springs flowing into *Quebrada Manzanares* were used as sources of water. The two contiguous springs farthest west, which formed the head of *Quebrada Manzanares*, belonged during the mid-1850s to Juan Calixto Rivera (AGPR-FOP-SG, Box 318, 1872) and later to Isidro Palmer. A well-curb with five outlet faucets and an iron-pipe inlet was built with public funds at the main spring, called *Fuente San Luis* (AHMSG-FOP, Box 5, 1866). Water-carriers filled hogsheads at the public *fuente*, and used ox-carts to peddle the water along city streets (Mejia-Lagarde, 1987). The springs to the east belonged to Nicolás de Quinones, later to

Ramón Saturnino Quinones and, by 1890, to Angel Antongiorgi (AHMSG-FOP; Box 5, 1894).

Quebrada Manzanares presented problems to the growing town. Its channel, 6 to 12 feet deep, and 4 to 10 feet wide, was considered dangerous, especially near homes and streets. Street crossings required bridges or culverts. During heavy rainstorms, Quebrada Manzanares often undermined bridges and roadbeds, and its lower, northerly course flooded Calle Javilla and its vicinity. During the latter part of the 19th Century, it became polluted with human and animal wastes.

COVERING QUEBRADA MANZANARES

Quebrada Manzanares was covered by segments in a haphazard manner from its waterhead to the Calle Javilla crossing by means of brick (and later concrete) vaults. The first covered segments corresponded to bridges and culverts (with spans smaller than 10 feet) built for street crossings. (See footnote.)

The arch bridge belonging to Calle Cruz, the oldest documented structure over Quebrada Manzanares, dates from before 1835. Around that date, Pascual Antongiorgi, a large sugar producer, builder and businessman who owned a house which bordered on this bridge, had it extended about two meters behind his land in order to protect his property from flooding waters (AGPR-FOP-SG; Document 222, 1872). Calle Cruz extended south,

---

The only "bridge" built over Quebrada Manzanares is the 10-foot span at the Calle Cruz crossing.

beyond the San Germán urban area, to become the road to the neighboring village of Lajas. In 1847, the city council Acts record a request for repairing the roadbed over this bridge (AHMSG-Acts 10; 1847).

Pascual Antongiorgi appears on another document as a builder or contractor conducting repairwork on damage done by Quebrada Manzanares when it overflowed Calle Comercio in 1846 (AHMSG-Acts 9; 1846). We infer from this document that a culvert already existed at this crossing, where Calle Comercio and Calle Javilla merge. A vaulted brick culvert at the crossing of Calle Luna was finished in 1851. A culvert for Calle Carro was designed in that same year with a budget of 252.37 pesos (AHMSG-Acts 11; 1850-52). It was finally built in 1853 by Ramón Genaro Porrata under the supervision of Martin Albertucci (AHMSG-FOP; Box 3; 1841-70).

There is a record of a permission granted in 1853 by the city council to a private citizen to cover the Quebrada Manzanares streambed across his property and to build over it. The citizen, Ramón Saturnino Quinones, alleged that the culverts at the Calle Carro and Calle Principe Alfonso crossings would be protected if the length of streambed between them was covered (AHMSG-FOP; Box 3; 1841-70). Although this particular block-length of Quebrada Manzanares was not actually covered at this date, this type of request was repeated during this period.

In 1858, it was reported that some citizens favored covering all the urban part of Quebrada Manzanares for flood control and safety reasons. They argued that this was desirable due to pollution and health problems, claiming that the city should pay for covering it. The council argued that adjacent property owners were actually covering it segment by segment and that in the future the whole length of the stream adjacent to or within the urban area would have been vaulted over (AHMSG-Acts 14; 1858). By this date, the land between *Calle Luna* and *Quebrada Manzanares* was being granted or sold to private citizens.

As early as 1867, stormwater inlets were being built at the southern corners of *Calle Luna* and *Calle Cruz* to collect and conduct this water under *Calle Luna* and into *Quebrada Manzanares* (AHMSG-Acts 20; 1867). This started the conversion of *Quebrada Manzanares* into a drainage system.

By 1872, bridges or culverts existed for the following street crossings: *Calle Cruz*, *Calle Luna*, *Calle Carro*, *Calle Principe Alfonso* (now *Calle Alfonso XII*), *Calle Ramas*, *Calle Esperanza* and *Calle Javilla*, at its junction with *Calle Comercio* (now *Calle Santiago Veve*). All of these structures, except for the culvert under *Calle Esperanza*, were paid for by the municipality. The *Calle Esperanza* culvert was paid for by Juan Calixto Rivera. This man owned a farm south of *Calle Luna*; his access road was an extension of *Calle Esperanza*, and the *Quebrada Manzanares* crossing occurred within his lands (AGPR-FOP-SG, Box 318, 1872). At that same date there were vaulted segments of streambed within the properties of Celedonio Besosa, Ramón Acosta and Tomás Fraderas, whose subsequently remodelled house is presently the Hotel Parador Oasis. There was another vault adjoining the *Calle Cruz* bridge, between the properties of Salvador Tió and the Diaz-Milán sisters (AGPR-FOP-SG; Box 318, 1872).

A year later, the city council approved a project to correct the course of a part of Quebrada Manzanares which was eroding the Calle Luna roadbed, east of Calle Carro. The roadbed was to be repaired, and the streambed moved away from Calle Luna, with its banks protected by retaining walls (AHMSG-Acts 26; 1873). At that time there existed several streambed retaining walls built by private citizens with property adjacent to the stream (AGPR-FOP-SG, Box 318, 1872).

The upper part of the stream, within the Rivera farm, was unpolluted. When water became scarce at other sources, people would enter this property located to the south of Calle Luna to use the Quebrada Manzanares water. In order to avoid problems with illegal entry, Rivera ceded the streambed and the land between it and Calle Luna to the municipality in 1879 (AHMSG-FOP-Box 5; Rec. 1879).

In 1888, the city council considered a proposal to create an underground waste water sewer system which would drain into Quebrada Manzanares (AHMSG-Acts 41; 1888). It was argued that such a system would be healthier than the surface drainage of waste waters, which eventually ended up in the stream anyway. Although this proposal does not appear to have been officially approved, the waste system did get to exist. Some neighboring property owners built small, vaulted brick waste drains connecting to open or to covered sections of Quebrada Manzanares.

The railway section passing south of San Germán was under construction in 1892 (AHMSG-Acts 45; 1982). It crossed Quebrada Manzanares just north of Fuente San Luis, and a culvert consisting of a brick vault upon stone walls was built for this crossing. A similar, but higher, culvert was built for the stream crossing through the Antongiorgi property, to the east of the San Luis spring. The railway grade required cutting the slopes of Ancones mountain, which meant stopping *Calle Cruz* just short of the railroad; this made it necessary to extend *Calle Esperanza*, making it the new exit to Lajas (AHMSG-Acts 45, 1892). As a result of the cuts and embankments made for the railway, several springs which had supplied water to the citizenry were lost (AHMSG-FOP, Box 5, 1894).

By c.1910, *Quebrada Manzanares* was covered at the following places: just beyond its headwaters by the culvert under the railroad tracks which had been extended north beneath the adjacent *Calle Ferrocarril*, from about *Calle Central* to the north and east beyond the crossing under the corner of *Calle Esperanza* with *Calle Tetuán* (AHMSG-Acts 61, 1911), at the crossing under *Calle Luna*, under the house of Ulises López Carlo (formerly of Tomás Fradera); at the crossing of *Calle Cruz,* continuing under the houses and commercial building of Ramón A. Torres and Franscisco Lagarde and the *Calle Carro* crossing, through to the *Calle Alfonso XII* crossing to the house of Santiago Rivera on the northeast corner of that street with *Calle Luna*; at the *Calle Ramas* crossing and under the Servera store (present site of the Yamil Galib mansion), and, finally, at the *Calle Javilla* crossing (Mejia-Lagarde, 1987).

In 1911, a segment of concrete tunnel extending 23 meters south of *Calle Tetuán* was built by contractor and master builder

Sebastián Barea and paid for by the township. It replaced a triangular arrangement of concrete pipes, placed c.1909, but which had been displaced by a flooding *Quebrada Manzanares*. Just a few days after the $100 payment, a new flood destroyed almost half of the new segment, the northernmost part adjoining the brick culvert under *Calle Tetuán*. The mayor then commissioned another builder, Barón Capriles, to rebuild this part, and to add 28 meters of additional concrete channel in order to connect the twice-destroyed length of tunnel to the vaulted culvert already existing under Calle Ferrocarril. Parts of this channel (probably the crossing under Calle Central) were to be provided with a concrete vault (AHMSG-Acts 61; 1911). This job, which cost $300 and included a two-inch thick cement mortar floor upon compacted gravel, still stands.

Repairs done in brick to the tunnel in 1907 required twelve laborers (at 50 cents per day) plus five bricklayers, three oxcartmen, one foreman and a master builder (AHMSG-FOP; Box 4, 1907). Repairwork done since c.1915 has used mostly concrete.

By 1930, all of the creek was covered, from its headwaters to beyond *Calle Javilla* (U.S. Geological Survey Aerial photo, 1930 set). By this time, the urban area extended well to the south of *Calle Luna*. When the land north of *Calle Santiago Veve* was developed by the Vivoni brothers c.1950, they had to cover *Quebrada Manzanares* from that point down for over 100 meters. This was done by means of a rectangular concrete culvert.

Master builders and contractors mentioned in the documents studied as having built tunnel segments include: Barón Capriles, Pascual Antongiorgi, Ramón Genaro Porrata, Segundo Vega, Martin Albertucci, Félix Acosta and Sebastián Barea.

Many legal problems occurred through the years during which the vault segments were put up. In some cases, adjacent owners had built retaining walls to protect their stream-banks, and they did not allow their neighbors across the stream to use their mansory walls as a base for vaults to cover the stream for the neighbor's benefit.

In some instances, rich citizens tried to use public health and safety considerations as reasons for the township to grant them land next to Quebrada Manzanares by promising to extend the vault through their property. The township considered the stream-bed to be public domain (AGPR-FOP-S.G.; Box 318, 1872), and it sometimes negotiated permits requested by adjacent property owners to cover the stream and use the space above. The space above vault segments built by the township between 1907 and 1908 were sold at $6.00 per square meter (AHMSG-Acts 58, 1908).

Originally, the tunnel (stream) floor was paved with stones (AHMSG-FOP; Box 4, 1893). Making the sliding wood form which was used for laying the parallel, contiguous brick arches for the vault was said in 1903 to require two half-days work by a carpenter, and to cost $4.00 (AHMSG-FOP, Box 4, 1903). The vault recess observed in many tunnel segments would have facilitated the use of such form work.

Most repairwork done up to c.1915 was in brick, although cement was being considered for use in sidewalks as early as 1904 (AHMSG-FOP, Box 4, 1904), and the above-mentioned 1911 replacement section was all in concrete. There are advertisements on cement brands in San Juan publications dating from 1894.

In 1911, the city council, prompted by health and smell conditions, had to prohibit additional sanitary sewer connections to Quebrada Manzanares unless these would carry enough water flow to ensure proper drainage of solid wastes (AHMSG-Acts 61, 1911). Current documents called the vaulted creek a sewer system (cloaca). In 1928, sanitary conditions were so bad that when a five meter long section of the vault caved in after a heavy rainstorm, it was considered a grave health emergency, and a thousand dollar loan was obtained by the township to pay for repairs, which were to be done using concrete (AHMSG-Acts 70, 1928). Most of the waste water connections to the tunnels have been eliminated since a true sanitary sewer was built c.1940.

The city is reminded of the existence of this system only when some part of the vault fails. This occurred last around 1978, producing an eight-foot diameter hole which required closing Calle Alfonso XII for several months. A 48-inch diameter concrete pipe was used to replace the caved-in vaulted brick branch conveying the Antongiorgi stream under Calle Luna and Calle Alfonso XII into the main tunnel.

An inspection of the main tunnel reveals many repairs. Repairwork done in brick is hard to detect, especially since construction patterns change almost every instance that the vault crosses under a property line. For example, although a 1894 repair costing 230 pesos on the Calle Esperanza culvert is documented (AHMSG-Acts 47; 1894), a visual inspection of the structure does not reveal its location with certainty.

TWO HISTORICAL CONCLUSIONS:

One objective of this study was to find out the purpose for which the tunnels were originally built. Another was to locate original drawings of the system.

1- ORIGINAL PURPOSE OF THE TUNNELS:

Under Farmacia Cooperativa drugstore the tunnel widens to 122 inches, then to 148 inches beneath adjacent Calle Cruz. These are the largest spaces in the Quebrada Manzanares tunnel system. The tunnel which continues downstream is only 57 inches high and 40 inches wide (See Drawings, Sheet No. 12). The fact that such a large conduit drains into a much smaller section, when a drainage system is expected to increase in size downstream, has made previous observers speculate on whether the tunnel system had other uses such as storage of contraband, escape route, or hideout (Visión, 1988; Feliciano, n.d.).

However, from the information provided by this project, we can conclude with certainty that the system's only original purpose was to cover Quebrada Manzanares while allowing storm water to reach it. The 148 inch wide space is the span of a vaulted bridge built before c.1835; it was not meant to be a chamber.

Manzanares being a common stream, its bed had both wide waterholes and narrow parts, while its banks ranged from high to low. During the 19th Century, with no earthmoving equipment but with plenty of cheap labor and inexpensive native materials such as brick and lime, it was more economical to vault over the stream-bed as it was than to alter its shape into that of a logical drainage system.

The specific 122 inch wide and 108 inch high section west of the Calle Cruz bridge was originally a large waterhole with deep banks. It is represented in a sketch map (See Figure No. 2) done in 1872, when it was partly covered and partly open. It is described in a contemporary document as a dangerous, gaping hole next to the Calle Cruz bridge (AGPR-FOP-SG; Box 318, 1872). In any case, if anyone ever tried to store something or to hide in these subterranean chambers, he would have had to deal with dangerous flash floods which occur in these tunnels everytime it rains in San Germán, which is quite often.

2. ORIGINAL DRAWINGS

No 19th Century drawings were found of the tunnel system. The reason is that the tunnel system was never designed. There are drawings of bridges and culverts, however. These were the original structures which later became connected by tunnel segments covering Quebrada Manzanares within private properties.

The variations in physical characteristics of the tunnel are incompatible with a planned drainage system. So are many of the transitions between segments of different sizes and shapes. Some of these transitions obviously violate principles of hydraulics.

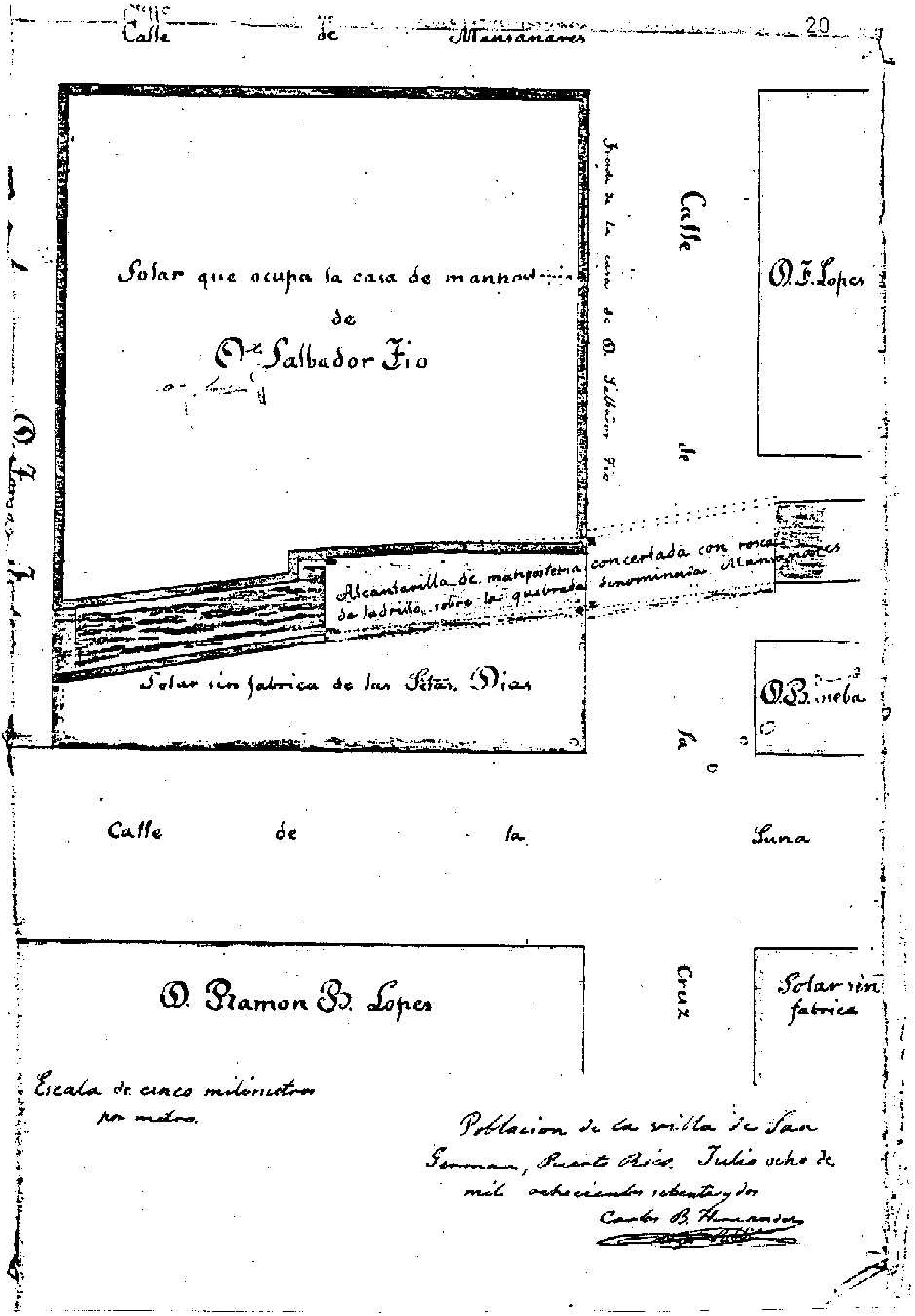


FIGURE 2

OPEN AND VAULTED SEGMENTS OF QUEBRADA MANZANARES NEAR CALLE CRUZ IN 1872 (AGPR-F.O.P.-S.G.; BOX 318)

DETAILED DESCRIPTION OF THE MAIN TUNNEL:

ANCONES TO CALLE LUNA:

One may enter the upper end of the Quebrada Manzanares vaulted brick tunnel system through a storm water inlet trench at Calle Ferrocarril, about 6 meters west of Calle Esperanza (See Drawings, Sheet 2).

A six-foot drop through the trench drain leads into a vaulted brick tunnel with a concrete floor. The clear but contaminated one inch-deep water flows rather swiftly along its center due to the sharp slope.

The tunnel actually begins 13 meters south (upstream) of this access, at a storm water manhole which receives spring and storm waters from farther south through a rectangular concrete culvert, and from east and west through concrete pipes. The southernmost 12 meters of brick vault were built c.1892 (See "Historical Background") by the Compania Ferrocarrilera de Puerto Rico, a French company licensed in 1888 to build and operate a railroad which was to circle the island (Pumarada-O'Neill, 1982). This structure, with cut-stone walls and a brick vault (See Photo No. 1) allowed Quebrada Manzanares to flow under the railbed; it is typical of other railroad drainage structures remaining in the area.

The segment under Calle Ferrocarril, with its brick vault resting on plastered walls (made of either adobe brick or rubble-and-lime-mortar) was probably built between 1892 and 1910. It leads into a rectangular concrete section, only 36 inches high

(See Photo No. 2), which crosses under the property located at the northwest corner of Calle Ferrocarril and Calle Esperanza. The rectangular construction ends at a serious constriction caused by a foundation column which projects halfway into the tunnel (See Photo No. 3). A higher, vaulted section, also in concrete, follows. Upon reaching Calle Central, the Quebrada Manzanares tunnel turns slightly east. The concrete segment under this street, which has a recessed vault, dates from 1911 (See "Historical Background"). So does the vaulted concrete segment to the north which crosses under a block-long property with a c.1911 sculptured concrete block home to reach the Calle Tetuán vaulted brick culvert.

These uncomfortably low, sharply-sloping vaulted concrete segments are nearly uniform in width. There are small patches of floor damage along their edges, and a long, deep gash in the center of the tunnel just south of Calle Tetuán. There are several changes in construction details, corroborating the records documenting that these segments were destroyed and rebuilt twice (See "Historical Background"). Several horizontal concrete inlets convey storm water into the tunnel from the west.

The Calle Tetuán culvert, made in brick, is older and much taller than the concrete segments which lead down to it (See Photo No. 4).

The Tetuán culvert, which probably dates from c.1895, is similar to the Calle Ferrocarril culvert in that both have horizontal vaults and sloping floors, but the Tetuán vault, unlike Ferrocarril's, is recessed, and has a steeper floor slope.

Beyond a relatively large hole in the floor of this culvert, a nearly uniform segment with a recessed, lower concrete vault runs beneath the western edge of three small properties facing Calle Esperanza, as if Quebrada Manzanares had been their western boundary. This segment ends just under the southern edge of the south sidewalk of Calle Sol.

A steel plate atop a gutter inlet at the south side of Calle Sol covers a narrow vertical 12-foot drop into the Sol/Esperanza vaulted brick culvert. A corbelled brick storm water inlet flares down (See Photo No. 5) into this culvert, which dates from before 1872. This straight, uniform recessed vault segment starts beneath the edge of the Calle Sol sidewalk, and heads northeast cutting diagonally across both streets. It passes under the property on the northwest corner. A second corbelled brick inlet connects to a gutter drain on the north side of Calle Sol, about two meters west of this corner, and a third such inlet connects to a gutter drain at the east side of Calle Esperanza, but neither of these inlets allow access to the tunnel system.

Northeast of Calle Esperanza, the tunnel is also made of brick and has a recessed vault, but it becomes slightly narrower and turns almost due east, then north-northeast, then east-northeast, then northeast, approximately coinciding with property divisions east of Calle Esperanza (See Drawings, Sheet No. 1). A waste water pipe discharging on the west side is guarded by a cohort of cockroaches. These segments have uniform width and recessed vaults, but slight changes in height and some structural discontinuities indicate that there may have been more than one builder involved, probably between 1885 and 1895. The west wall and the vault near the lower end of the section oriented to the northeast shows extensive and unsightly repairwork, done in concrete with corrugated iron sheets (See Photo No. 6).

Upon approaching Calle Luna from the south, the floor slope decreases. The segment just downstream of the repair patch mentioned above, is lacking the floor slab because of channel erosion for the next 20 feet, and Quebrada Manzanares drops about 12 inches down into a sizeable waterhole which is about 24 inches deep (See "Structural Integrity").

Just above the center of this waterhole there is a vertical access through a 24-inch square patio drain which is covered with an iron bar grille and a piece of plywood. This access is located in the backyard of a structure located west of the parking lot of the Presbyterian Church, south of Calle Luna (See Drawings, Sheet No. 1). Two meters beyond this waterhole, a small permanent stream joins Quebrada Manzanares from beneath the Presbyterian Church parking lot to the east.

This segment ends in a "Y"-shaped chamber, where it is joined by another permanent stream (Torres-Oliver, 1988) entering through a smaller vaulted brick culvert coming from the north side of Calle Luna (See Photos Nos. 7 and 8). A drainage trench along the western edge of the Presbyterian Church parking lot discharges into this chamber through an opening on its east side, located between the chamber's vault and the lower vault of the downstream tunnel. This opening is negotiable for access.

Beyond this chamber, the tunnel heads east, gradually approaching Calle Luna. Under the south sidewalk of Calle Luna, the tunnel becomes the vaulted brick culvert which crosses perpendicularly under this street.

The geometry of the two culverts crossing under Calle Luna, corresponds to that of an 1850 sketch (See Figure No. 3). Since no record of subsequent construction or reconstruction was found for any Calle Luna culvert, we assume that both existing culverts were the ones built c.1851.

CALLEJON FORES TO CALLE JAVILLA:

At the downstream end of the larger, northbound culvert, under the sidewalk of the northeast corner of Calle Luna and Callejón Forés, there is a small chamber with a higher vault and smoothly plastered walls, from which Quebrada Manzanares again turns east.

The first segment of this easterly course of the main tunnel is lined with original stream-bed rocks on both sides for about 5 meters. Beneath the city block between Callejón Forés and Calle Cruz, the tunnel remains straight, gradually diverging northward from Calle Luna. The segment beneath the original Oasis Hotel building (formerly the Fradera home) dates from c.1860. Its floor slopes down, away from an apparently horizontal vault, increasing the tunnel height from 72 to 117 inches. Under Farmacia Cooperativa drugstore (located in what was the property of the Diaz-Milán sisters in 1872), the tunnel widens to 122 inches (See Photo No. 12). Then it merges into the pre-1835 Calle Cruz

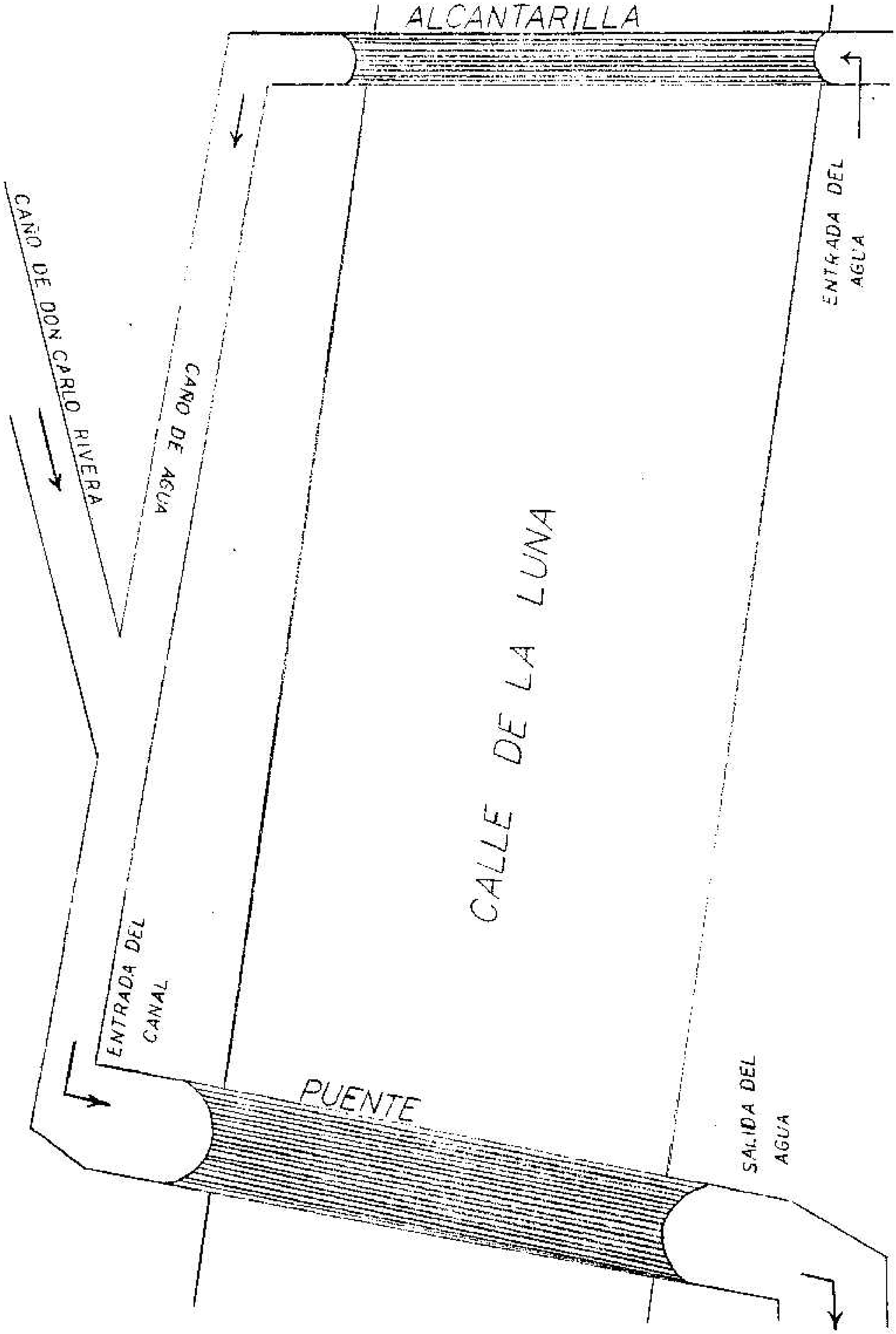


FIGURE 3
1850 DRAWING FOR CULVERTS UNDER
<u>CALLE LUNA</u> (AHMSG -F.O.P.; BOX 9, 1850)

vaulted bridge, which spans 148 inches (See Photo No. 13). Two brick drainage structures discharge storm water from Calle Luna and Calle Cruz into this bridge segment, these must be the original structures built in 1867 (See "Historical Background"). The floor of this chamber-sized bridge section shows extensive damage.

The tunnel segment which leaves downstream is only 57 inches high and 48 inches wide. Leaving from the north side of the 144 inch wide end wall of the previous segment, it has the appearance of an opening into a room--a perception that has baffled many observers, who see a contradiction between the relative size and position of this downstream tunnel segment and the function of a storm sewer system (See Photo No. 13 and "Historical Background"). This segment crosses under a store which was once connected to the commercial building just to its north. Both buildings belonged around the end of the 19th Century to the same owner (Torres Oliver, 1988). A series of conspicuous and unsightly concrete repair patches and some embedded stream-bed rocks appear on the north wall of this section (See Photo No. 14). This length of tunnel, with a vaulted roof which steadily becomes higher as the floor slopes down, ends at a northward bend where the vault steps up to a height of 62 inches.

The next segment, located beneath the residential property facing Calle Manzanares which at the turn of the century belonged to merchant Francisco Lagarde (Mejia-Lagarde, 1987), remains 48 inches wide, but has a recessed vault. This vault is only 1/2 brick thick. Just east of the bend there is a corbelled brick vertical inlet, to the top of which there is connected a 4-inch diamater vertical pipe which may be a roof drain. This inlet is similar to, but not as complex as, the ones at the intersection of Calle Esperanza and Calle Sol. This segment ends at a slight bend, on a diagonal projecting arch, beyond which the tunnel steps up in height from 72 to 112 inches and in width from 50 to 86 inches (See Photo No. 15).

This ample segment is lined with stream-bed rocks (See Photo No. 16). Similar rocks were said to have been once dislodged and carried downstream by flood waters; they had to be eventually hammer-crushed "in situ", since it was impossible to move them and they could not be permitted to remain blocking the stream (Mejia-Lagarde, 1987). This segment gradually narrows down just beyond the rocks to a height of 85 inches and a width of 65 inches. This tunnel segment, the ones following it down to Calle Carro, and the one just beyond its street culvert, were built by merchant Francisco Lagarde between c.1895 and c.1910, as he expanded his flourishing business (AHMSG-FOP C&S, Box 16, 1896, AHMSG-FOP C&S, Box 17, 1909, Mejia-Lagarde, 1987). The Lagarde building once above this segment has made way to a parking lot.

The next segment runs under an old Lagarde storehouse (today subdivided among several tenants) which has cellars and sunken patios, and its vaulted roof steps down about 20 inches. This part has an access opening, 30 x 36 inches, framed in iron (See Photo No. 17), used for maintaining (repairing and clearing) the tunnel segments belonging to Francisco Lagarde (Mejia-Lagarde, 1987). The frame held a trap door. This access lies just west of a sunken patio which is accessible from a service ramp entering from Calle Luna. Nowadays, the patio and the entrance belong to a discotheque called "La Cueva de Luis Candelas".

As the Lagarde basements above became deeper, the vaulted roof stepped successively lower: as little as 45 inches in height downstream of the access door. There is evidence of raw sewage discharge in this section. Beyond, the tunnel grows slightly in size before having a minor constriction provided with end walls, after which the tunnel opens into a space 75 inches wide and 94 inches high (See Drawings, Sheet No. 16). This taller space lies under the eastern part of the old Lagarde building, which has no basement or sunken patios.

This tall segment merges into the Calle Carro culvert, which dates from 1853 (See "Historical Background", and Figure 4). The Calle Carro culvert's vault shows a dangerous crack across, and its floor is significantly damaged. It is joined from the north side, above vault level, by a horizontal vaulted brick branch which runs beneath Calle Carro, close to the west curb gutter (Personal observation of Puerto Rico Telephone Company excavations, 1987-88). There is seepage of waste water between vault bricks which may originate from a sewage pipe crossing above the vault. The culvert, which becomes 115 inches high and 76 inches wide, ends with its vault dropping 30 inches and with a constriction caused by the southern wall, just where it is joined by a horizontal vaulted brick storm water branch with a dangerous, extensively damaged floor (See Drawings, Sheet No. 17).

In the segment following the Calle Carro culvert, there is a

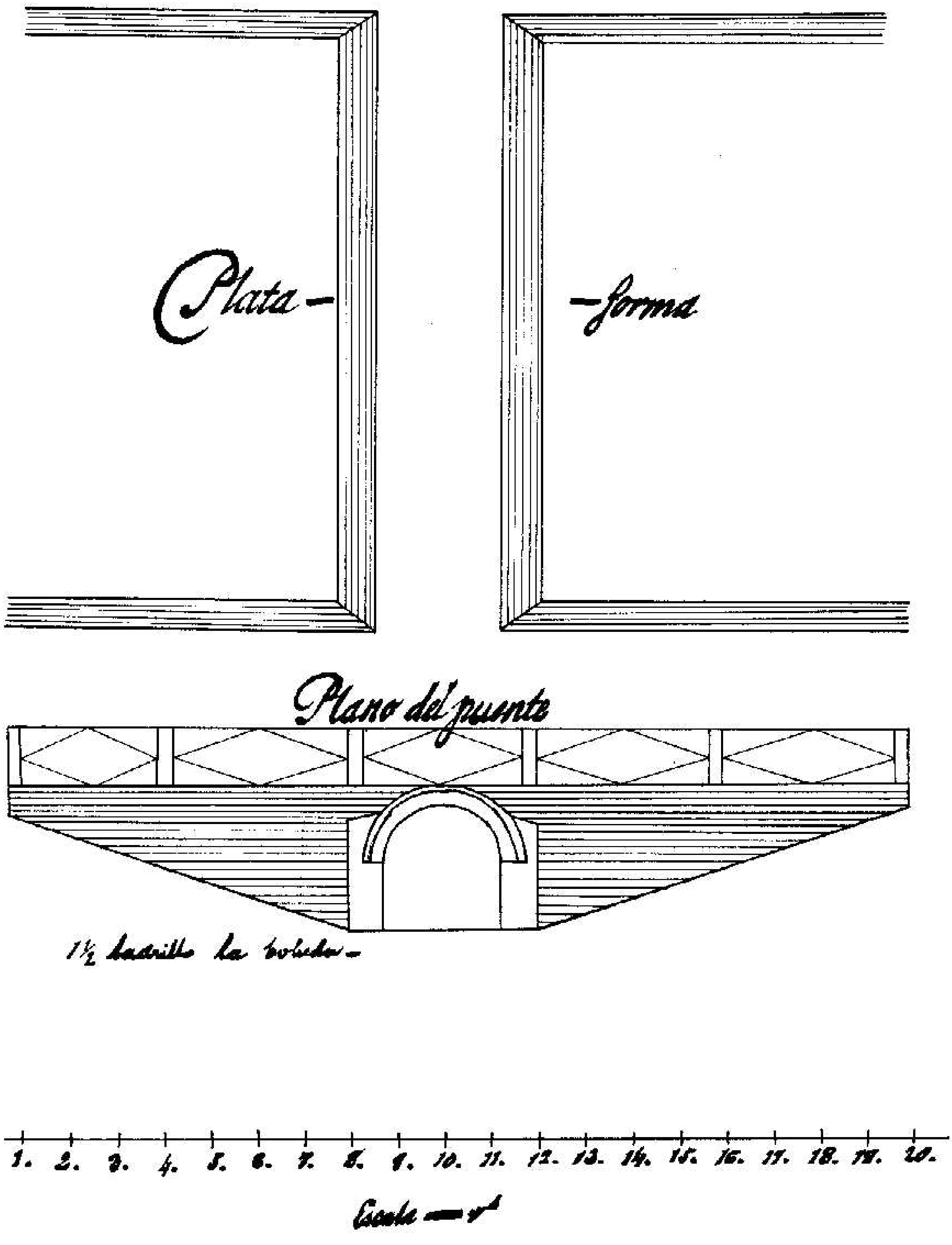


FIGURE 4

DRAWING OF CULVERT FOR CALLE CARRO

(AHMSG - F.O.P.; BOX 3, 1853-54)

vertical brick inlet with a hinged brick access door. Just beyond this feature, the vault has been replaced by a concrete slab for a length of about 7 feet. This segment was also built by Francisco Lagarde c.1905 (Mejia-Lagarde, 1987).

East of this slab roof, the tunnel averages just over 80 inches in height. It is characterized by slight misalignments and small variations in vault height.

In the section west of the Calle Alfonso XII culvert, the tunnel height is reduced to 72 inches. We believe that Ramón Acosta had his home above this section, and that therefore this part dates from before 1872 (See "Historical Background").

Upon reaching the c.1865 Calle Alfonso XII culvert, the southern wall flares out and the vault steps up, creating a space which is 110 inches high and 92 inches wide. This culvert has direct openings to curb drains on the street above. Its upstream end shows structural damage on the vault.

A horizontal vaulted brick branch, about 58 inches high, brings the permanent waters of Quebrada Antongiorgi from the south to join those of Quebrada Manzanares within this culvert (See Photo No. 18). This branch, which runs under the west side of Calle Alfonso XII, collapsed about 10 years ago, interrupting traffic for several months. The collapsed length, and the contiguous part crossing under Calle Luna were replaced by a 48-inch diameter concrete pipe. This stream comes down from beyond an old railroad culvert within the Antongiorgi property; it enters a rectangular concrete conduit which conveys it into the c.1860 vaulted brick culvert about 7 feet south of Calle Luna. There is extensive, dangerous floor damage in this important branch just beyond the downstream end of the concrete piping (See Photo No. 19). A street drain on the northwest corner of the intersection of Calle Luna and Calle Alfonso XII provides access to this branch and, through it, to the main tunnel.

At the east end of this culvert, the height of the vaulted roof comes down from 112 to 83 inches. In the tunnel segment beyond, under neath what was the property of Santiago Rivera, the floor slopes down relative to the roof, increasing the vault height to 102 inches at its east end. At this point, the north wall steps in to reduce the tunnel width from 83 to 58 inches. This constriction appears to have been modified by the addition of a headwall to improve flood-flow conditions (See Photo No. 20).

The tunnel beyond keeps fairly straight and uniform as it crosses under a property and then runs just south of the line dividing two properties facing Calle Luna from those facing Calle Santiago Veve to the north. Most of its 1/2 brick vaulted roof has been replaced by concrete slabs, and there are instances of floor damage. The top of the vault here is almost flush with the ground level.

The tunnel again flares out when it becomes the Calle Ramas culvert, a c.1865 structure. This culvert has inclined instead of vertical sidewalls (See Photo No. 22). It is 100 inches high and 88 inches maximum width (at the vault recess). A dangerous crack runs accross the vault near the upstream end of the culvert (See Photo No. 21).

Just beyond this culvert, the vault drops to a stooping 55-inch height. This c.1880 segment was probably built by Servera Hermanos, a firm which owned a store and warehouse extending along the east of Calle Ramas, from Calle Luna to Parque Santo Domingo. It consists a 2-brick thick barrel vault with no sidewalls (See Photo No. 22). It becomes gradually lower as it passes under the Yamil Galib home (built by coffee and sugar cane producer Juan Ortiz Pericchi), which replaced the Servera store around 1915.

At the end of this low segment, the 47-inch high barrel vault gives way to a narrower tunnel with a concrete slab roof. (See Photo No. 23). This rectangular cross-section tunnel which remains about 24 clear inches below grade runs fairly straight and uniform in width, with its height increasing gradually to 84 inches at the next construction discontinuity. It is located just south of the line dividing the properties facing Calle Luna from those facing Calle Santiago Veve to the north. This part, which probably corresponds to the tunnel built by the city c.1907 (See "Historical Background"), receives a polluted flow of permanent water from the south through a vaulted brick branch, as well as some direct raw sewage discharges (See Drawings, Sheets No. 23 and 24). Near the end of this segment, the tunnel is joined by a rectangular concrete branch coming from street corner drains at Calle Luna. This branch can be entered from a parking lot on the north side of Calle Luna, across the street corner drained.

Just beyond this branch, the tunnel turns about 60 degrees to cross beneath the property of Sucesión Jaime Acosta, heading towards the intersection of Calle Javilla and Calle Santiago Veve. This segment again has a vaulted brick roof which is about 80 inches high.

Upon reaching the south side of Calle Santiago Veve, the tunnel turns slightly northward to become the culvert crossing under this streets intersection with Calle Javilla. This culvert is similar in height and construction to the preceeding section, but 10 inches wider. This c.1860 structure marks the end point of the original vaulted brick tunnel system.

CONCRETE ADDITION:

The Calle Javilla culvert has been extended in a rectangular concrete construction to the east side of Calle Vivoni. (See Photo No. 24). There it turns slightly northward, and its concrete roof slab becomes the east sidewalk along that street. At the entrance to the San Germán Health Center, Calle Vivoni turns east and the tunnel crosses to continue between this facility and the Ensanche Vivoni development, with its concrete slab roof now serving as a roadway.

The tunnel ends just beyond the health center property limits. It discharges a 36 inch high waterfall into a waterhole. Thus, Quebrada Manzanares becomes a surface stream until it reaches the Guanajibo River, about 200 meters to the north.

DRAINAGE BASIN

To trace the origin of several secondary streamflows to the main tunnel and the fate of some stormwater flows in order to establish the drainage basin limits, a dye called Pyla-Tel Fluorescent Green, manufactured by Pylam Products of Garden City, New York, was used. This dye is known by the generic name of Fluorescein.

Originally, an "optical brightener" type of dye was to be used, but it was discarded due to background interference resulting from a high concentration of detergents in the tunnel water. Optical brighteners are normal components of detergents. The concentration of brighteners present in the water could have caused the dye tests to be misleading. The test performed to determine the concentration of brighteners in water is described in a paper by Quinlan (1976).

Figure 5 shows the drainage basin of the San Germán tunnel system. The basin boundaries were determined by field observation and dye tests. The basin area was estimated to be 0.51 square kilometers (126 acres) by means of a planimeter.

A flow volume of 354 ft^3/sec was calculated using the rational formula ($Q = C\ i\ A$). A weighted average value of 0.49 was used for the coefficient of runoff. This value was obtained estimating two thirds of the drainage area to be covered by paved streets, dwellings and commercial buildings with an average runoff factor of 0.65, and one third covered by lawns and trees with a runoff factor of 0.15. A value of 5.8 in/hr was used for

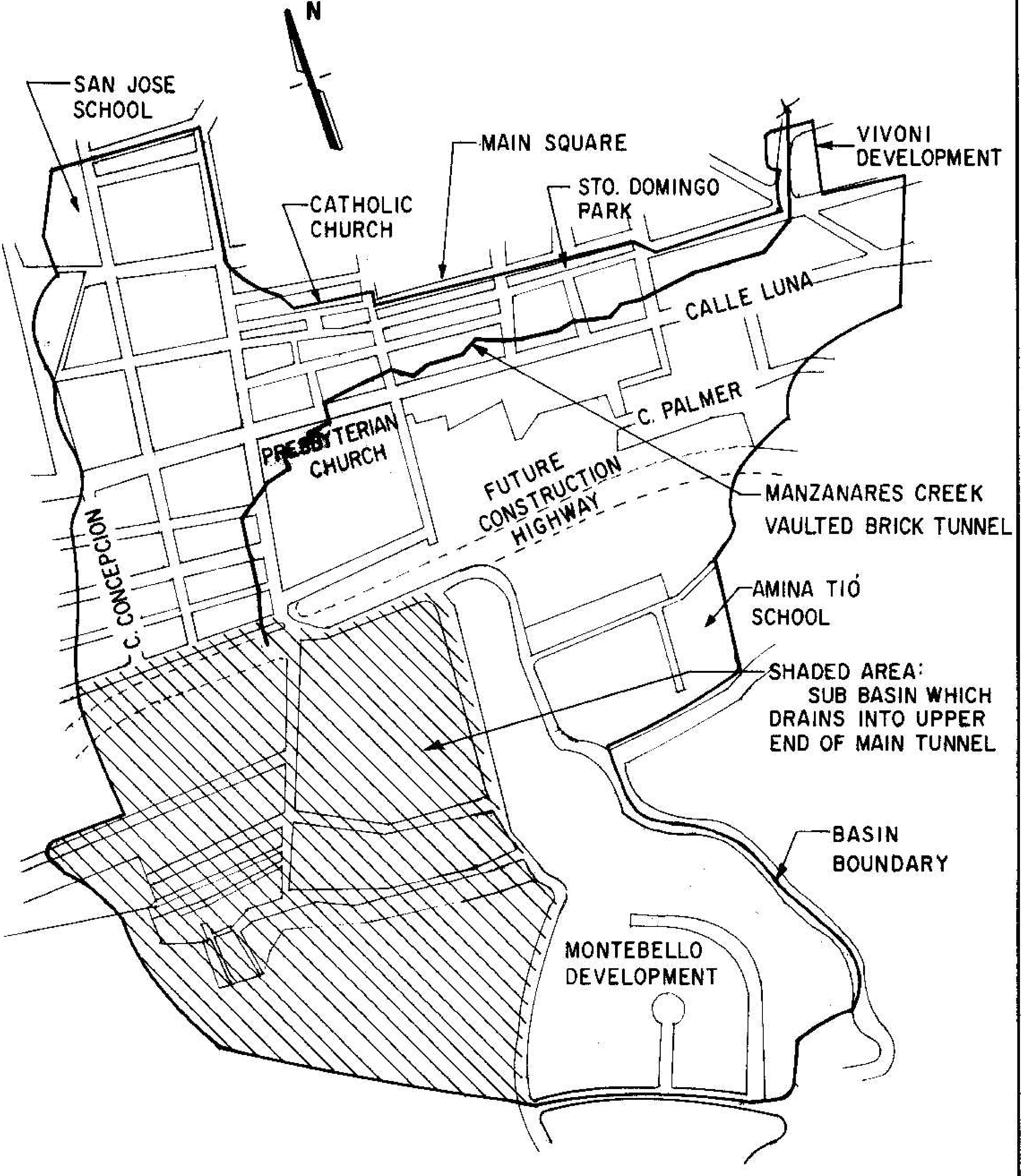


FIGURE 5:
MANZANARES CREEK
DRAINAGE BASIN

APPROXIMATE SCALE: 1:1,000

TOTAL APPROXIMATE
DRAINAGE AREA: 0.51 km^2

the rainfall intensity. This value was derived from the U.S. Department of Commerce- Tecnical Paper No. 42. (1961), based on a frecuency of occurrence of 10 years and a 30 minute rainfall duration.

The flow volume of 354 ft^3/sec would approximate the total volume discharged at the downstream point of the main tunnel, where Quebrada Manzanares becomes a surface stream. The existing natural stream channel is adequate for conveying this volume into the Guanajibo River.

The total volume calculated above reaches the main tunnel at different points along its 842.53 m length. Although the main tunnel varies in crossection repeatedly, it is reasonable to state that it has adequate capacity for these flows (See "Physical Characteristics"). The floods known to occur at some points of Calle Luna are caused mainly by reduced appurtenances to the main tunnel and the ineffective location of some drains. These problems have to be corrected if the flood conditions are to be eliminated.

In order to establish if the tunnel crossection at the upstream portion has adequate capacity to handle present and the potential additional flow volume, the portion of the basin that drains into the uppermost point of the tunnel was determined. This portion has an area of approximately 32 acres, one fourth of the whole basin. The flow volume calculated for this area was 56 ft^3/sec, using the rational formula. Since this area is covered mostly by forest and by crowded housing and it has a steep slope, an average coefficient of runoff of 0.30 was used (Hammer, 1975).

Using the above flow volume and an average flow velocity of 10 ft/sec a conduit with crossectional area equal to 5.59 Ft^2 would be required. The uppermost segment of the tunnel has an average crossectional area of 9.75 ft^2 which is sufficient.

Although the above analysis demonstrates that the tunnel has enough capacity at present, changes in land use patterns in the drainage area could bring a higher flow into the tunnels. For example, if the basin is developed and the terrain cover is changed to one having a higher coefficient, such as between 0.70 to 0.95 for a commercial area, the new estimated volume would be 130 to 176 ft^3/sec, which would exceed the capacity of this part of the tunnel.

It can be stated that under the present conditions the tunnel crossection is sufficient to handle the water flow volume. The flood problems in some streets, and the constriction in crossection caused by a building column in the upper portion of the tunnel (See Drawing No. 3 and Photo No. 3) are problems that can and should be solved.

WATER QUALITY

One of the objectives of this project was to study the use of part of the Quebrada Manzanares tunnel as a tourism attraction. In order to comply with this objective, the quality of the water running permanently through the main channel had to be established. During the visual inspection of the system, several sewage discharge pipes were observed (See Drawings). The discharges appear to come from individual houses and commercial buildings. The presence of feces and bad odor was evident in their vicinity. The discharge is subsequently carried by the stream. For establishing the water quality quantitatively, a composite sample was taken from 10:00 AM of July 23 to 10:00 AM of July 24, 1987, at a point just below the Cueva de Luis Candela sunken patio access (See Drawings-Sheet No. 15). The sample was transported to Caribbean Research Laboratories (known as OMNI Laboratories) at San Germán for analyses. The parameters analyzed and the results obtained are presented in Table 1.

The results show that most of the parameters are within acceptable limits, except for fecal coliforms and dissolved oxygen (DO). The presence of fecal contamination was confirmed by a fecal coliform concentration in excess of 2400 MPN/1000 ml. The desirable limit for secondary contact water for fecal coliform concentration is 2000 MPN/100 ml or less. "Secondary contact" refers to those situations in which contact with the water is either incidental or accidental, and the probability of ingesting appreciable quantities of water is minimal (1). This would be the case if the tunnels were to be visited by tourists.

Table 1

Quebrada Manzanares Water Quality Analyses

Parameter	Result	Parameter	Result
Temperature (F)	81.1	Color (Pt Co)	2
pH	6.65	Dissolved Oxygen (DO)	3.8
Turbidity (ntu)	7.9	Biochemical Oxygen Demand (BOD)	7.4
Total Suspended Solids	11.3	Chemical Oxygen Demand (COD)	19
Total Dissolved Solids	5	Fecal Coliform $(^{MPN}/100$ ml	>2400
Total Solids	16.3	Total Coliform $(^{MPN}/100$ ml	>2400

Note: All values in mg/l unless otherwise indicated.

The DO concentration is used as on indicator of pollution by organic waste. Table 1 shows a DO concentration of 3.8 mg/l, which is below the recommended minimum DO concentration in free-flowing streams, which is 4 mg/l.

Based on the results obtained, it can be stated that: *the permanent streamflow through the tunnels is contaminated and direct contact with the water should be avoided*. *Corrective measures to eliminate this situation should be taken if a segment of the system is to be used for tourism*.

The sample mentioned above was taken during the rainy season, when the permanent flow is usually higher and pollutants are more diluted. During this period the system is washed thoroughly during each storm event, maintaining it clean of debris and of accumulation of solids at damaged floor waterholes. During the dry season (from January to March) it is expected that the pollution of the system becomes worse due to the low permanent flow.

Table 2 shows the sewage discharges detected along the tunnels. This information, together with the photos, could serve as references to locate the sewage discharge points.

---

1. *Water Quality Criteria*, National Technical Advisory Committee, Federal Water Pollution Control Administration, Washington, D.C., 1968.

Table 2

Detected Sewage Discharges

Sheet No.	Discharge Detected	Comments
2	Presence of Sewage in Spring Water	Presence of sewage in the spring water as evidenced by bad odor and decomposition of organic matter.
8	4" DIA. Cast Iron Sewage Pipe	
10	4" DIA Cast Iron and 3" DIA. PVC Sewage Pipes.	
11	Vaulted Brick Branch	Frequent waste water discharges
15	6" x 6" Waste Water Inlet	
16	3" DIA. PVC Waste Water Inlet	
17	Waste Water Seepage	Wastewater enters through the vault ceiling below Calle Carro, probably from leaking street sewage pipe.
20	8" x8" Waste Water Inlet	
23	3" DIA Cast Iron and 4" DIA Waste-Water Inlets	
27	2-10" DIA Waste Water Pipes	Pipes crossing the tunnel but with no discharge in them.

STRUCTURAL INTEGRITY

These are many points along the tunnel system where the concrete channel floor has been removed by erosion, especially at the upstream half of the system due to its steep slopes. More

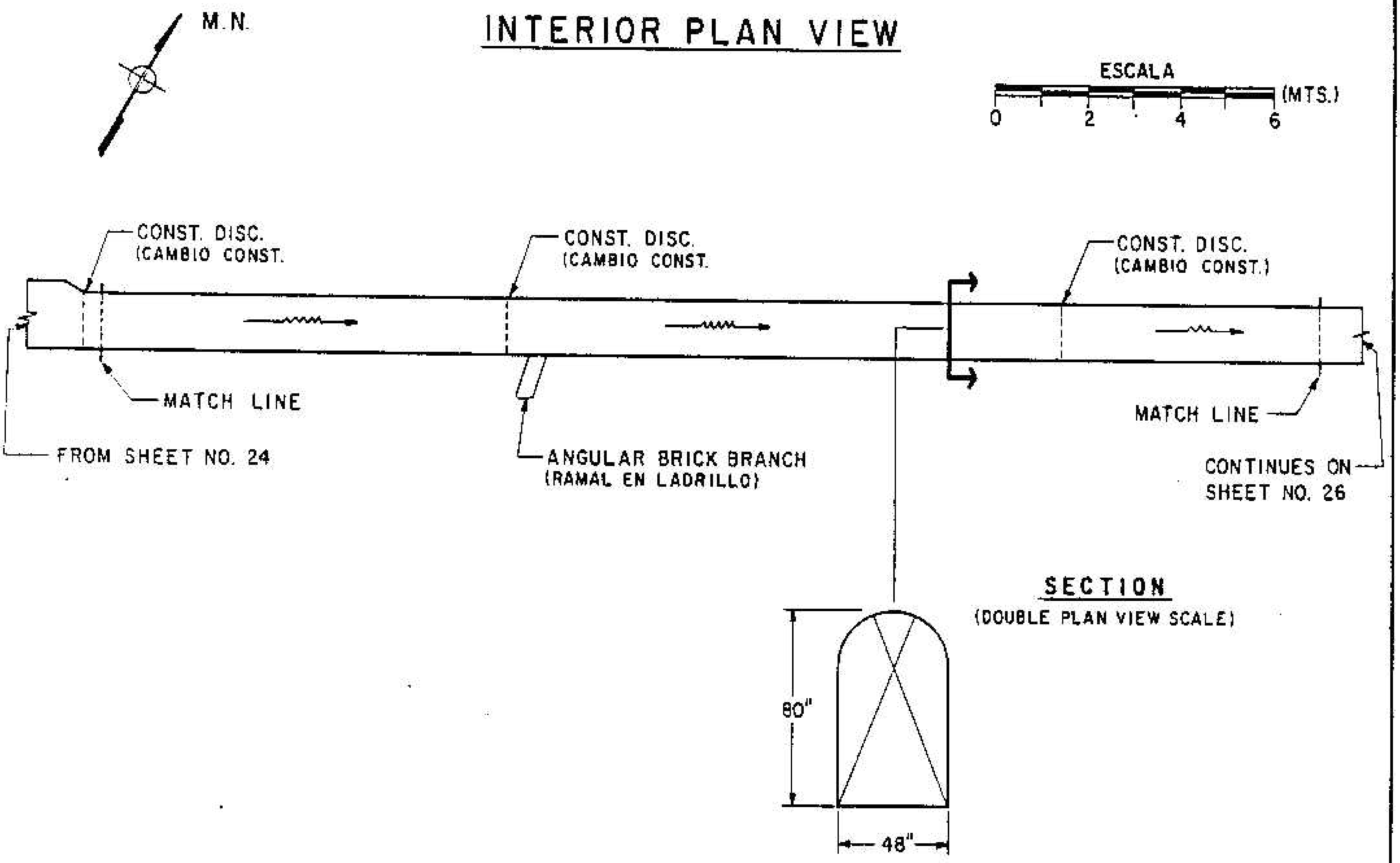
Table 3

Detected Structural Problems

Sheet Number	Situation Detected	Description and/or Comments
3	Damaged Floor	Portion of the channel floor eroded at base of walls under Calle Central.
4	Damaged Floor	A segment of about 3.5 m in length is eroded along the floor centerline possibly due to change in channel material.
5	Damaged Floor	Channel center floor eroded at two points.
6	Damaged Floor	Floor eroded at two points and the vault broken at one point under Calle Esperanza.
7	Damaged Floor	Floor eroded under Calle Esperanza
8	Damaged Floor	A segment about 5 meters long is missing along channel center line.
	Damated Vault and Patched Wall Segment	Damaged Vault and Walls Corrugated Zinc Patched Segment. Storm and sewage discharges occur at the upper end of this damaged section. The wall at right side looking downstream is displaced and the vault is damaged.
9	Damaged Floor	6.0 meters of floor and channel material completely eroded, forming a pool about 2 feet deep.
	Missing Bricks in Vault	Missing bricks in vault leave opening to space under the floor of a building on Calle Luna.

10	Rocks embedded in channel floor	Rocks in channel bed could produce channel erosion.
	Damaged Floor	Damaged Floor segment begins at a sewage discharge point.
11	Damaged Floor	Floor eroded of a small segment under Parador Oasis.
12	Damaged Floor	A great portion of channel floor is eroded. The tunnels change in crossection four times in segment approximately 25 m long. This is the longest damaged floor segment in the main tunnel.
13	Concrete and corrugated iron patches at the north wall	Patches along north wall show the kind of corrective work patches done in the past.
14	Rocks embebded in channel floor	Increased turbulence could cause scouring and affect structural integrity.
17	Damaged Floor	Floor removed at one point beneath Calle Carro, and within a brick branch coming from the south side.
20	Damaged Floor	Floor damaged at one point.
21	Damaged Floor Broken vault ceiling and crack on vault	Floor damaged at one point, Vault broken are repaired some time ago, it shows a crack at the cost end of the segment.
22	Crack on Vault	Vault portion shows a crack about one half inch wide.
27	Damaged Floor	Floor eroded at two different places under Calle Vivoni sidewalk.
30	Channel Bed Erosion	There is a pool formed due to channel bed erosion.

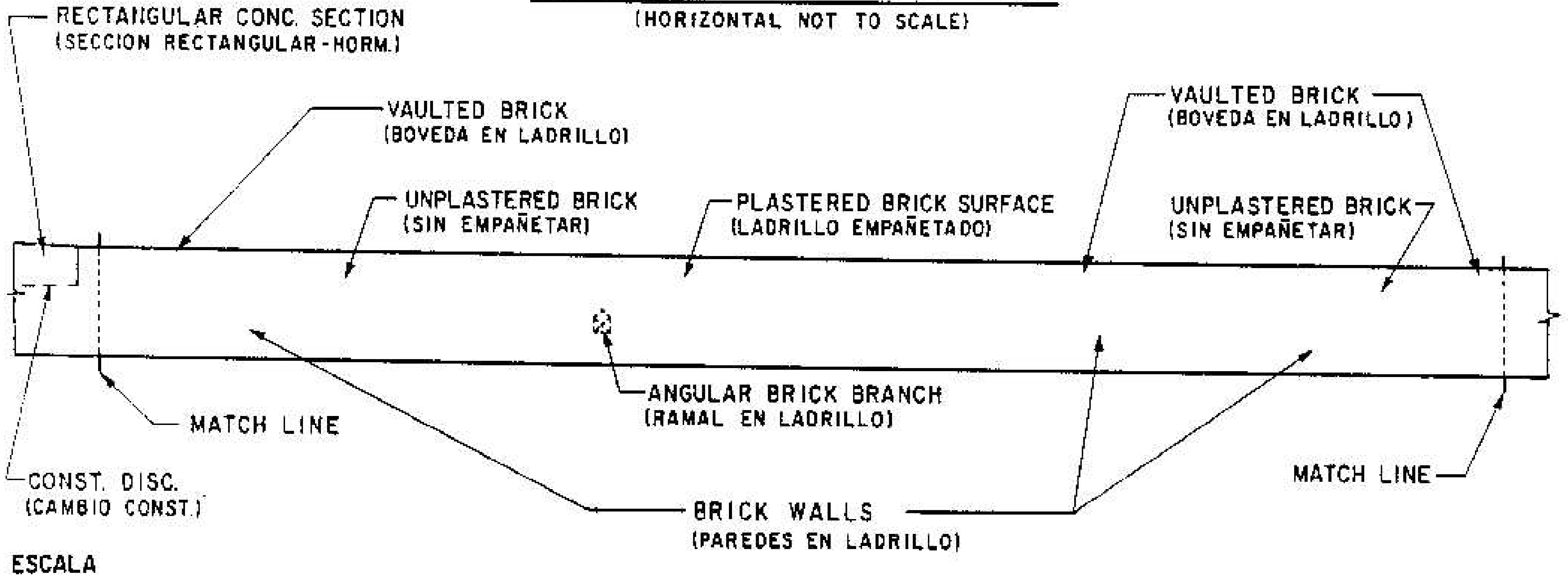
INTERIOR PLAN VIEW

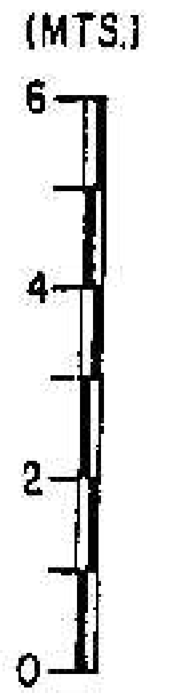


SECTION
(DOUBLE PLAN VIEW SCALE)

INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





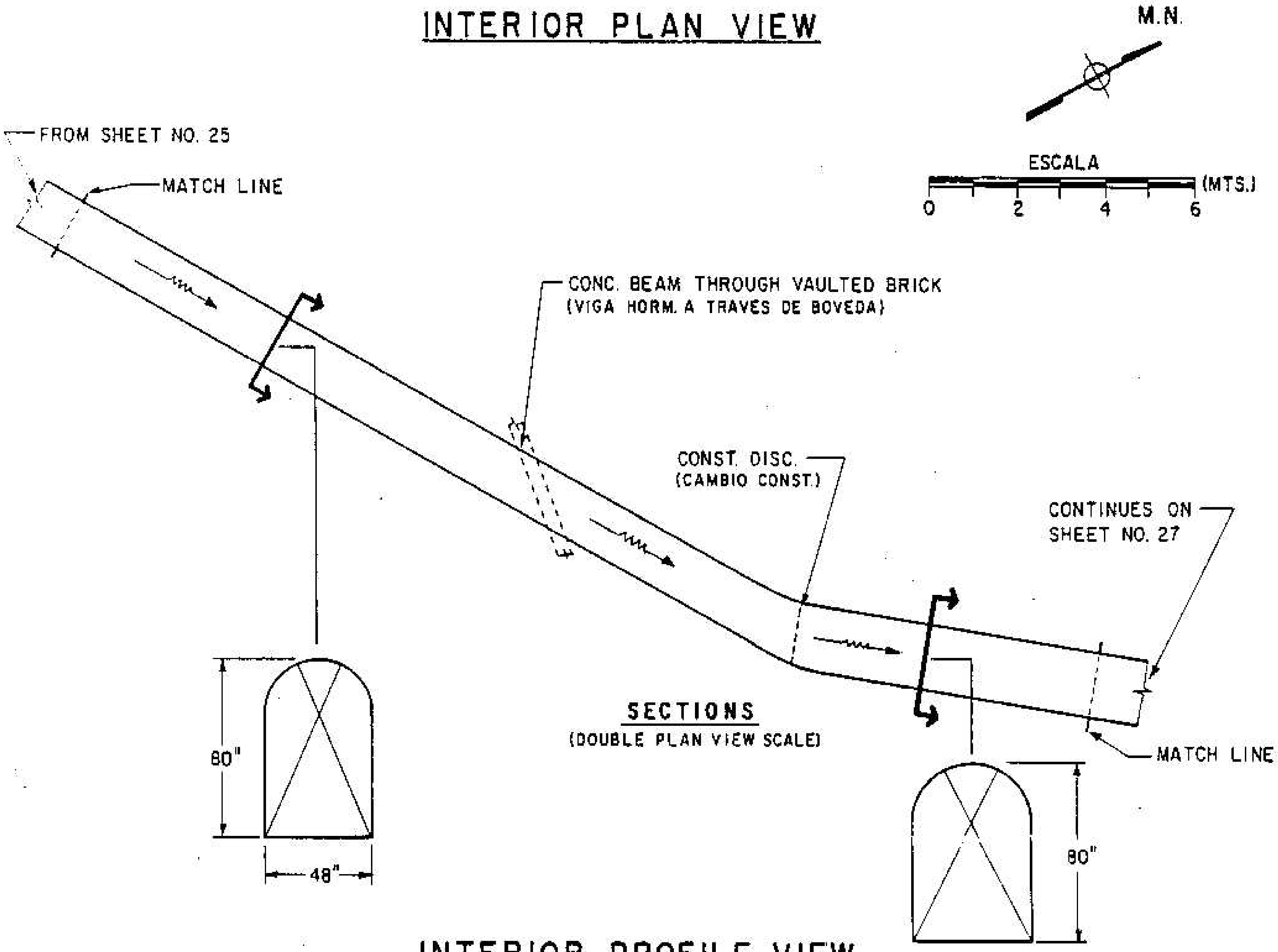
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

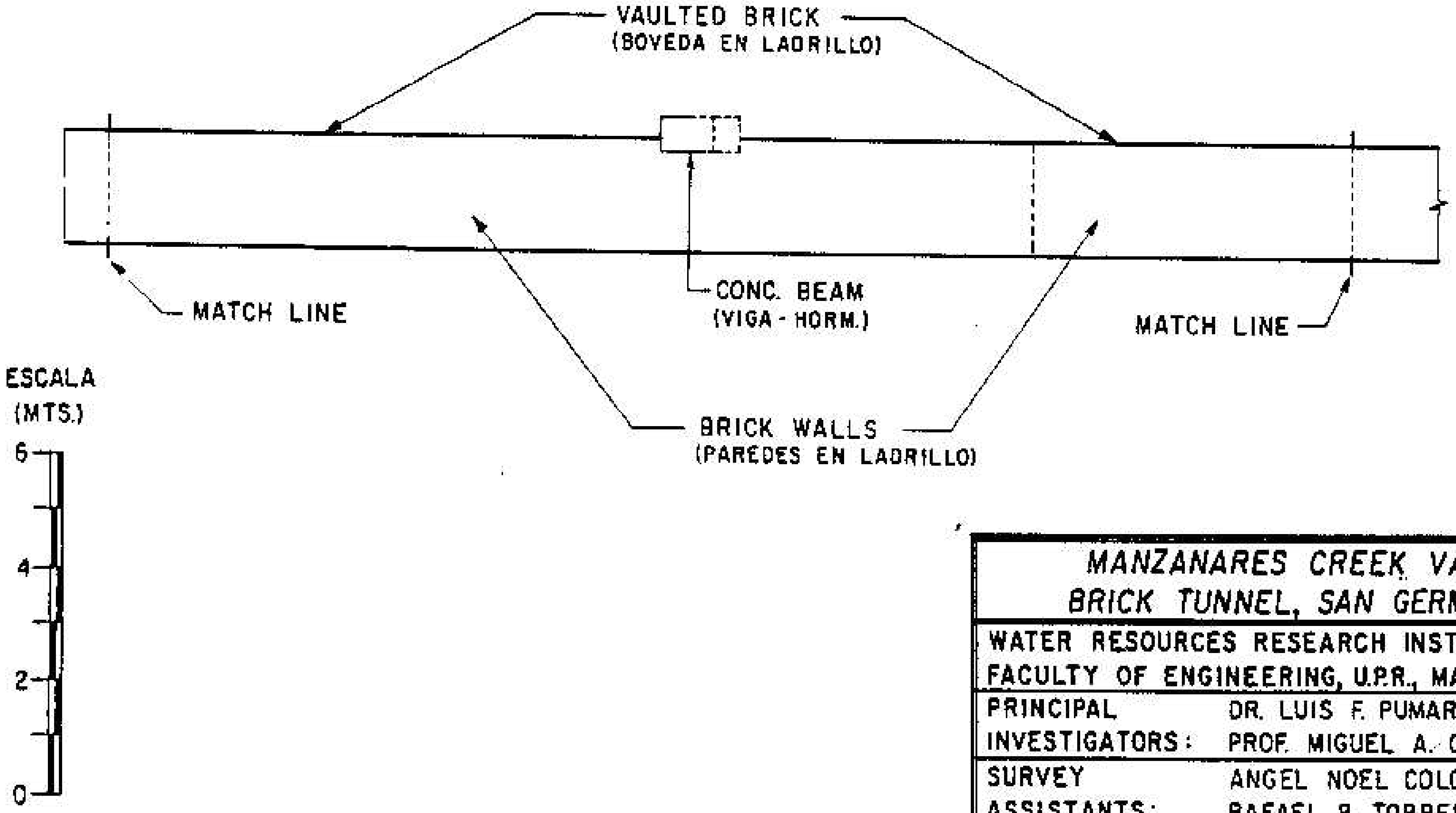
MAY-DECEMBER 1987

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



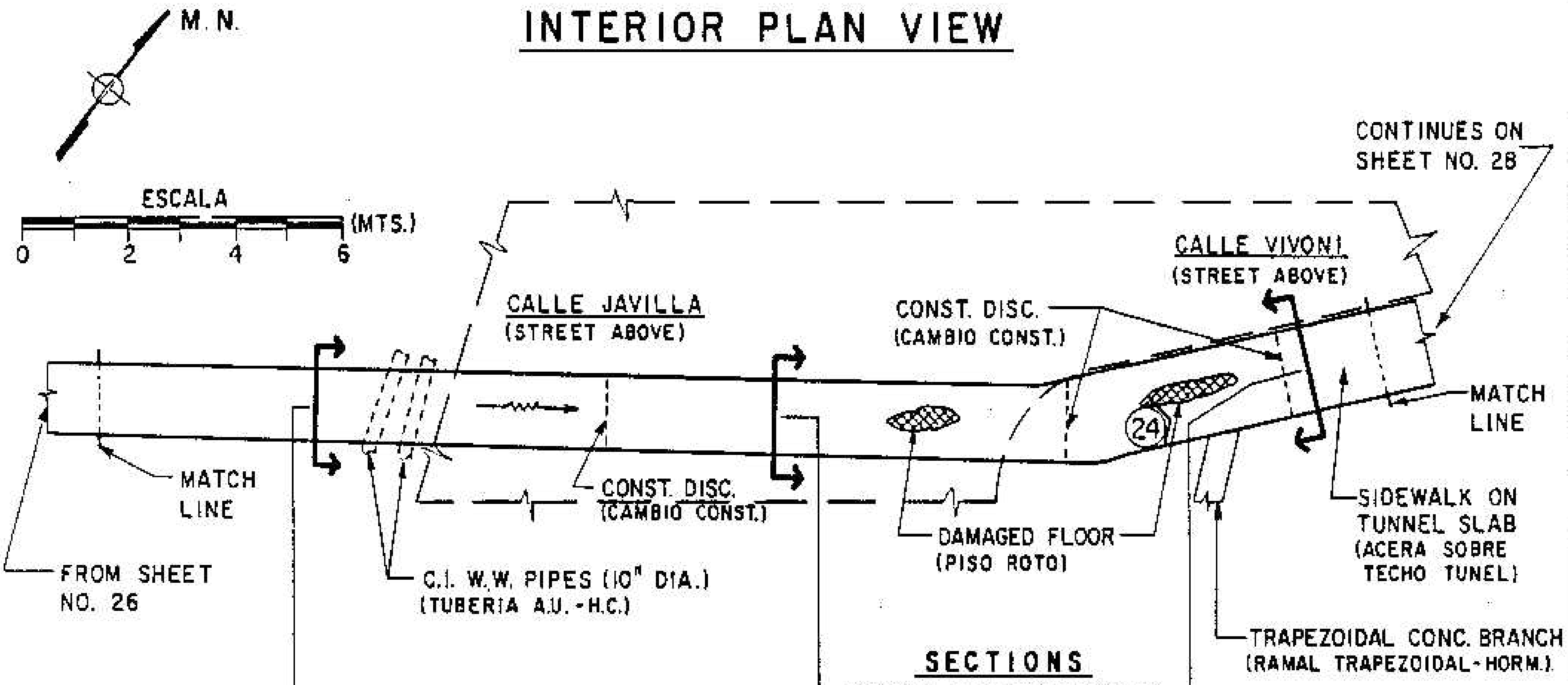
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

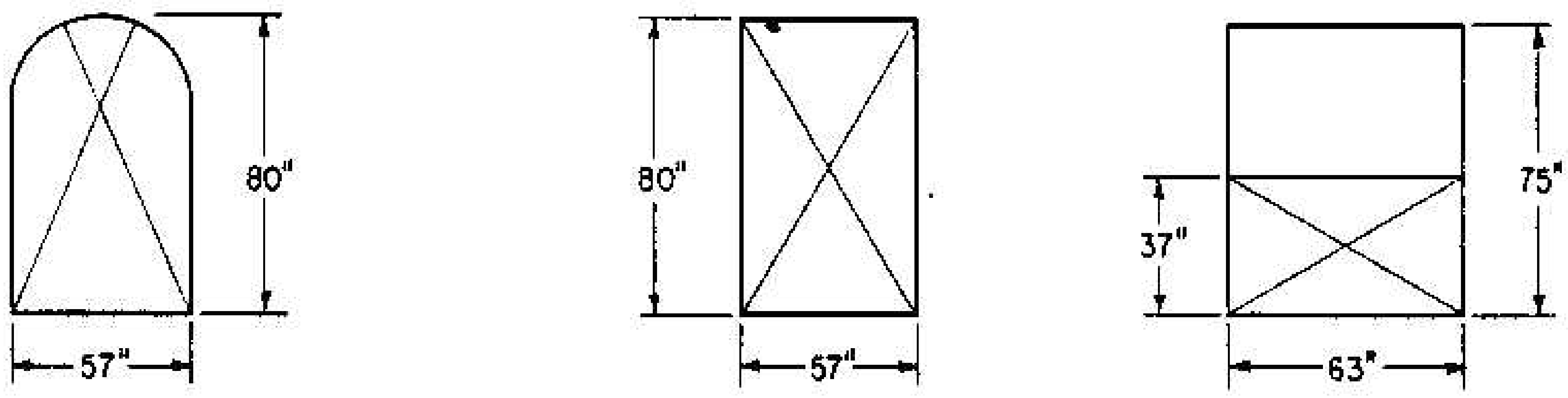
MAY-DECEMBER 1987

INTERIOR PLAN VIEW



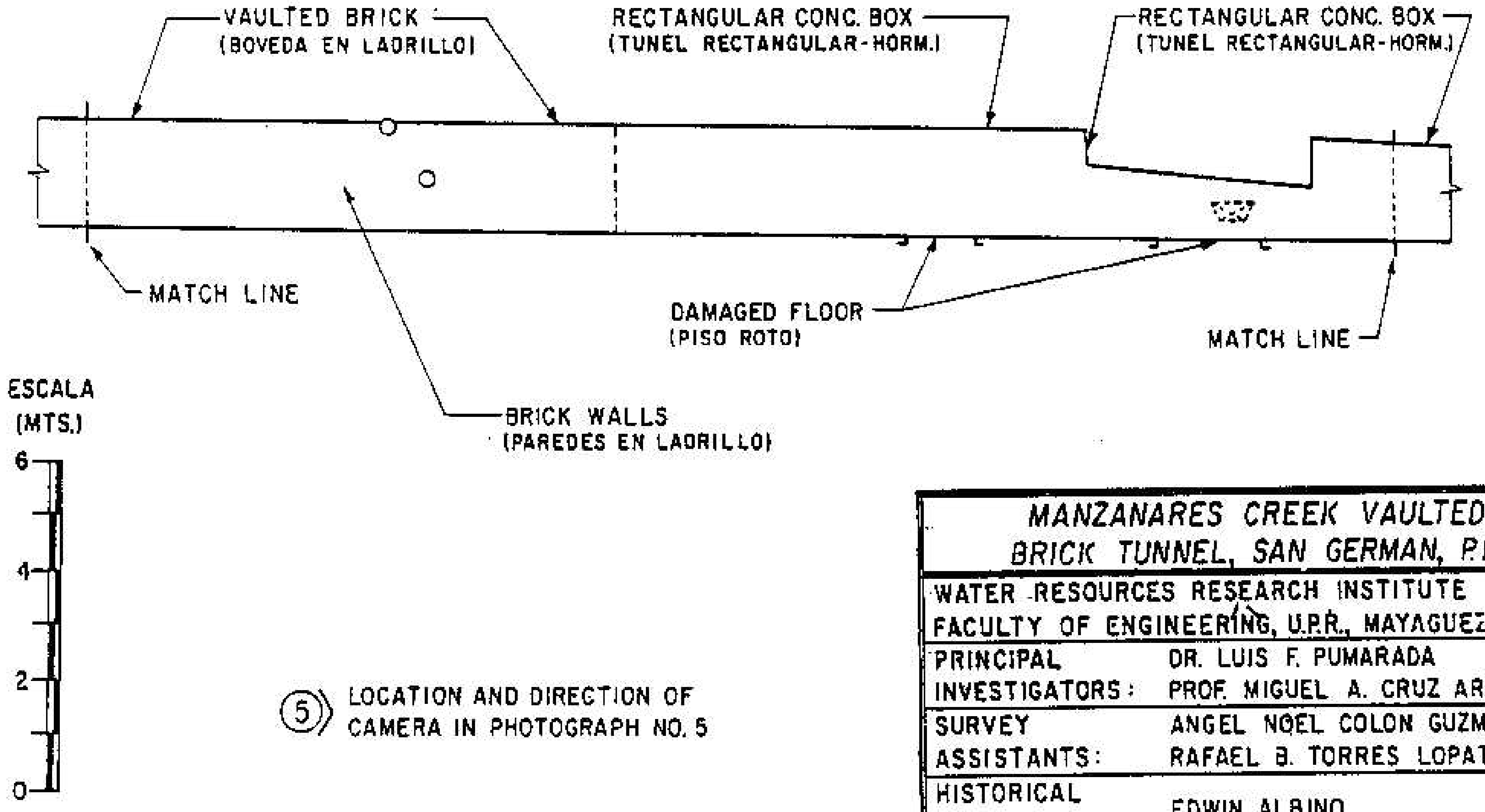
SECTIONS

(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER, 1987

27/30

TOURISM DEVELOPMENT

DESIRABILITY OF DEVELOPMENT:

The San Germán vaulted brick tunnel is definitely a potential tourism attraction. It has many segments of positive visual impact and many parts which can be easily walked through. The legends on its uncertain origin and the continuous variations of its physical characteristics combine with an inherent darkness to provide an attractive air of mystery and adventure.

Tunnel visitors would learn about 19th Century Puerto Rico, urban development forces and processes, and the significance of technical matters on daily life.

The city of San Germán is an established tourism site because of its historical remains, facilities and relative accessibility. This infrastructure can favor and support an influx of tunnel visitors.

Combined with such present and projected San Germán historical tourist attractions as Porta Coeli Chapel and the parks built around it, the projected Railroad Station museum, the Lola Rodriguez de Tió home, the recently innaugurated Ramirez de Arellano Home Museum, the Old City Hall, the centuries old Catholic Church, and the projected Bahr Home crafts center, the "historic adventure" type of attraction provided by a well-designed development of this tunnel could turn San Germán into a big tourism magnet. The set of attractions mentioned here would invite overnight visits and turn the city of San Germán into the tourism headquarters from which to sample the magnificent south-western beaches.

OBSTACLES:

There are several obstacles which must be overcome in order to convert the Quebrada Manzanares vaulted system into a tourism attraction:

- There are many unsightly and foul-smelling raw sewage discharges. These illegal discharges attract cockroaches to their vicinities and they cause pollution to Quebrada Manzanares and the Guanajibo River. The polluted water creates an undesirable environment for visitors.
- The tunnel floor is damaged in many spots, causing difficulty and danger to foot travelers and threatening to undermine the tunnel as well as the streets and structures above and around it.
- Existing roof cracks and lateral displacements also threaten the safety of the tunnel and what lies above. Moreover, a collapse of a segment of the tunnel could scare visitors away, while an urgently repair would probably disreguard historical preservation considerations.

The above conditions must be corrected urgently because of other reasons: pollution control, continuity of storm water drainage and safety of surrounding streets and buildings. We assume, therefore, that these urgent problems will be solved promptly whether the tunnels are touristically developed or not (See "Recommendations").

However, even after these conditions were corrected, there would still remain several obstacles for tourism development.

1. There are interspersed low-ceiling segments which make movement difficult.

   The segment under the Oasis Hotel is the most upstream one which allows a person to walk erect. The segment under Calle Javilla is the one farthest downstream. Between them, there are two segments as low as 45 inches, which almost require a person to crawl. One of these segments is west of Calle Carro, the other is just east of Calle Ramas.

   Short segments as low as 60 inches could be negotiated by stooping without undue discomfort by visitors provided with hardhats.

   The lowest-roof segments may be traversed by visitors seated in vehicles. On the other hand if there was no storm water flow in the tunnels (See No. 5 below), the floors of these segments could be excavated to lower them and allow suitable walking clearance.

2. The tunnel carries a permanent flow of water, which makes walking difficult and and prone to slipping.

This problem could be solved at a reasonable cost by diverting the permanent flow into a pipe buried under the present tunnel floor, starting at the intersection of Calle Luna and Callejón Forés and ending at some point below the end of the tourism segments. The hydraulic and structural feasibility of this alternative should be studied.

3. The tunnel is dark.

Tourism development would require artificial illumination. This could be achieved at a reasonable cost.

Well-designed artificial illumination could highlight the most visually appealing parts, while hiding unsightly patches and unrestored parts in near darkness.

4. There are instances of conspicuous unsightly repairs which detract from the tunnel's visual impact.

Some repairs in corrugated steel and concrete project significantly into the tunnel space and are too obvious for concealing by subdued lighting. The development of those segments which include such patches would require the restoration or modification of these spots.

5. The tunnel floods almost instantly everytime it rains, making it a dangerous place to be in.

This is the most serious drawback for tourism development. It leaves two choices:

a- Develop only a short, easily traversed length of tunnel which can be speedily evacuated whenever it treatens to rain, and provide it with one or more flood-proof shelters or emergency exits. Limit visitors to guided tours of less than 20 minutes. No tours would begin whenever rain was thought possible. An alarm would sound if it ever began raining while people were inside. This alternative would require a minimum investment, but it would not be very attractive for tourists.

b- Build a new parallel storm-sewer system beneath Calle Luna, and abandon the use of the developed length of tunnel for that purpose. This alternative would require a major outlay of funds and worsen the Calle Luna traffic problem while the works were done, but it would have the added benefit of providing San Germán with a better storm drain system. Diverting the storm water and the permanent flow would permit the unrestricted development of a good length of tunnel. Coupled with good support facilities and management and a well-designed illumination sytem, it could make the Quebrada Manzanares tunnel as attractive to visitors as the very successful Camuy River Caverns Park.

6. The comparatively few and small openings provided for storm water inlets do not provide the minimum ventilation area required for a space to be used by people.

DEVELOPMENT POTENTIAL OF DIFFERENT SEGMENTS:
Oasis Hotel to Luis Candelas Discotheque:

The 126-meter length of tunnel between Hotel Parador Oasis and the sunken patio at the Cueva Luis Candelas discotheque (See Photos 9 through 17, and Drawings 10 through 15) has no segments under 60 inches high, except for a 17 meter long segment which is 57 inches high. Most of it can be walked through erect. It includes the largest "chamber" in the tunnel, the Calle Cruz bridge, which is at the same time the oldest documented component. There are also some large streambed rocks (See Photo No. 16) and some puzzling structural transitions (See Photo No. 15).

At the corner of Calle Luna and Callejón Forés, across from the hotel, there is an undeveloped property which could be used for access and surface support facility. Across Calle Luna from this property there is a school parking lot which could be made available for visitors on weekends. The discotheque access could be made into an emergency exit.

Calle Carro to Calle Ramas

From the segment just west of Calle Carro down to where the Calle Ramas culvert joins the attractive double-brick barrel vault under the Yamil Galib home there are 144 meters with no part whatsoever under 60 inches high (See Photos 18 through 22, and Drawings 16 through 22). This length of tunnel is easier to walk through than the one above. It includes the confluence of Quebrada Angongiorgi with Quebrada Manzanares (See Photo No. 14), as well as several attractive transitions and large chambers (See Photo No. 20).

A part of the block-size, multiple-tenant building on which the discotheque is located and which fronts on Calle Carro, Calle Luna and Calle Manzanares lies above the western end of this length of tunnel. Part of this late-19th Century Lagarde structure could be attractively remodelled and used for access and surface support. There is a parking lot adjacent to this building. The matter of an emergency exit near Calle Ramas, however, would not be an easy one to solve.

There is another part of the tunnel which is 136 meters long with no part under 60 inches, located between the properly east of the Yamil Galib home and <u>Calle Javilla</u> (See Drawings 23 through 27, and Photos 23 and 24). However, this part is mainly straight and uniform, without attractive transitions, and much of its brick vault has been replaced by concrete slab. It would not be a good tourism attraction by itself.

RECOMMENDATIONS

Based on this investigation, we recommend that one of the following alternatives be implemented, based on the decision-maker's objectives and on additional studies.

JURISDICTION:

The following recommendations are directed to the city government of San Germán, since the tunnel works as a storm sewer system, which is normally under the jurisdiction of city governments. However, in this specific case, there are overlaps with private owners and with Commonwealth and U.S. agencies.

Originally, each person owning land above the Quebrada Manzanares tunnel was held responsible for the repair and maintenance of the part beneath his property. For that purpose, each segment had an access door.

Quebrada Manzanares being a free-flowing stream, even though two thirds of it now runs underground, it is under the protection of the Puerto Rico Department of Natural Resources, the Puerto Rico Environmental Quality Board and the U.S. Environmental Protection Agency.

Since most of the vaulted brick tunnel is over fifty years old, and it is a significant engineering, cultural and historic feature, it is potentially elegible for nomination to the National Register of Historic Places. This puts it under the jurisdiction of the Puerto Rico Office of Historic Preservation, and for these same reasons, it pertains to the Institute of

Puerto Rican Culture.

ALTERNATIVES:

The following are alternative sets of actions which can be studied for feasibility and considered for fulfilling objectives concerning the Quebrada Manzanares tunnel. Some of these actions are under the jurisdiction of bodies other than the San Germán city government, such as the Puerto Rico Highway Authority, and thus need backing on the part of the central government of Puerto Rico.

The actions in Alternative A should undertaken immediately; all others are optional.

A. The Minimum Feasible course of action which could fulfill the objectives of continuing uninterruptedly the level of service now given by this facility and complying with pollution control regulations would include the following actions

1. Structural stabilization:

This is the most urgent necessity, since many tunnel segments appear to be in danger of collapse. All damaged floors must be repaired to stop leakages and undermining of structures. Points where scouring could occur should be identified and preventive work undertaken.

A structural study should be conducted immediately, resulting in prompt actions to ensure a stable tunnel for the next 20 or 30 years.

2. Raw sewage clean-up:

   Those properties which still discharge raw sewage into the tunnel must be identified and their owners notified. Some present owners may not be aware of this fact. These discharges are illegal and must be removed.

3. Modify the drainage design of the projected highway (Southern by-pass) in order to divert part of the storm runoff from the Quebrada Manzanares basin to other basins

   The building of a highway on the slope of Ancones Mountain (See Drawings, Sheet No. 1) can be used to divert water to other streams, some of which have had their channels recently cleared and widened. This diversion would compensate the increase in storm flow which could result from the eventual development of the presently forested Antongiorgi property, located within the Quebrada Manzanares basin below the projected highway, and from the possible redevelopment of the Ancones district substandard housing above this highway.

4. Provide a permanent suitable access to the tunnel for inspection, maintenance and repair work, and set up a program for that purpose.

   There is no adequate access to the tunnel for workmen, tools, machinery and materials. This condition, which makes maintenance and repair work more difficult and more expensive, should be corrected at once. Periodic inspection visits should be instituted to monitor structural, hydraulic and pollution conditions.

B. Improved Drainage. This alternative would improve the level of service now provided by the Quebrada Manzanares tunnel. It would include executing the actions presented in the Minimum Feasible Alternative (A), plus

   1. Improving street drainage

      Providing larger, better located drains and more direct connections to the main tunnel from the intersections of Calle Luna and Calle Esperanza, Calle Luna and Callejón Forés and Calle Esperanza, Calle Popular and Calle Ferrocarril. However, since this may just transfer the occasional flooding which occurs at these intersections to other locations farther downstream by surpassing the capacity of lower tunnel segments, a hydraulic study should be conducted before implementing this action.

2. Convey into the tunnel the water from an apparent spring affecting the Calle Esperanza roadbed.

   There is a spot on the Calle Esperanza pavement which continuously holds water and is said to require frequent repair. This condition may come from the existence of a spring under the roadbed. This occurs at the intersection of Calle Esperanza with Calle Popular, about 10 meters south-southeast of the manhole on the southernmost point of the tunnel (See Drawings, Sheet No. 1).

   If it proves to be a spring, its water should be collected under the roadbed and piped into the Quebrada Manzanares tunnel.

3. Correct the constriction shown in Sheet No. 3 of the Drawings.

   A concrete body which appears to be a foundation column reduces the cross-sectional area of the tunnel to one half beneath the block located north of Calle Ferrocarril.

4. Modify significantly the drainage design for the projected highway (Southern by-pass) in order to divert a significant part of the water from the _Quebrada Manzanares_ basin to other basins.

   Once it was determined that other basins could absorb a significant part of the run-off now flowing within the _Quebrada Manzanares_ basin, a modified drainage system for the projected highway may be a feasible alternative to Action 1 above for improving flood conditions along _Calle Luna_.

C. Small-scale Tourism Development This alternative would provide a welcome but limited tourism facility at relatively low cost. It would require the implementation of all the actions mentioned in the Minimum Feasible Alternative (A) plus:

   1. Decide which of the two attractive, easy-to-walk parts of the tunnel to develop. (See "Tourism Development").
   2. Open a walk-down access into the tunnel, and provide proper surface facilities.
   3. Provide illumination.
   4. Install rain alarms.

5. Open an emergency exit or build a flood shelter at the point farthest from the entrance.
6. Restore conspicuous unsightly patches.
7. Divert the permanent water flow of the developed segment to a pipe placed under its floor.
8. Provide sufficient mechanical ventilation.

D. Large-scale Tourism Development and New Parallel Storm Sewer System This alternative is the most expensive, but it would provide a first-class tourist attraction and improve San Germán storm drainage. The limited development described in alternative C above could be a first phase of this alternative, until the new parallel storm water sewer was completed. It would require the implementation of all the actions in the Minimum Feasible Alternative (A) plus:

1. Decide whether to develop only the two most attractive, easy-to-walk parts or the whole Oasis to Calle Javilla length of tunnel.
2. Provide access facilities near the end points of the part developed, furnishing

one of them with the proper surface support, and the other to serve as an emergency exit and service entrance.

3. Choose between and implement either the use of small, electric train-like vehicles to carry a number of people through the tunnel, or excavate the floors of the low-ceilling parts within the developed tract in order to increase clearance and permit visitors to walk erect or nearly so.
4. Build a new storm sewer under Calle Luna to substitute the developed tunnel segments.
5. Seal present street drains into the tunnel.
6. Install an illumination system.
7. Restore conspicuous unsightly patches.
8. Provide sufficient mechanical ventilation.

REFERENCES

PRIMARY SOURCES:

AGPR; FOP-SG: Archivo General de Puerto Rico. Fondo de Obras Públicas, San Germán.

AHMSG: Archivo Histórico Municipal de San Germán:
Acts: - Libros de Actas de la Asamblea Municipal
FOP: - Fondo de Obras Públicas
C&S: - Fondo de Casas y Solares

SECONDARY SOURCES:

WRITTEN:

Feliciano, Héctor, "Los Túneles de San Germán", mimeographed, no date.

Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands. Technical Paper 42. U.S. Department of Commerce, 1961.

Hammer, Mark J., Water and Wastewater Technology, John Wiley, 1975.

Pumarada-O'Neill, Luis, Breve Historia de las Obras de Ingenieria de Puerto Rico, Colegio de Ingenieros y Agrimensores, San Juan, 1982.

Quinlan Jame F., "New Fluorescent Direct Dye Suitable for Tracing Groundwater and Detection with Cotton", Third International Symposium of Underground Water Tracing, Yugoslavia, September, 1976.

University of Puerto Rico, "Inventario Histórico de Ingenieria e Industria de Puerto Rico", Office of the President, 1977-78 (10 volumes).

Vélez-Dejardin, J., San Germán, notas para su historia, Puerto Rico Historic Preservation Office, San Juan (1983).

Visión, "Caracteristicas y usos de túneles subterráneos", 3 (51), April 15-29, 1988, pp. 15-23.

ORAL (INTERVIEWS):

Mejia-Lagarde, José, 1987 (taped)

Morales-Lugo, Waldemar, 1988

Selosse, Rafael, 1988

Tió, Aurelio, 1987

Torres-Oliver, Luis, 1988

Vivoni-Acosta, Alfredo, 1987

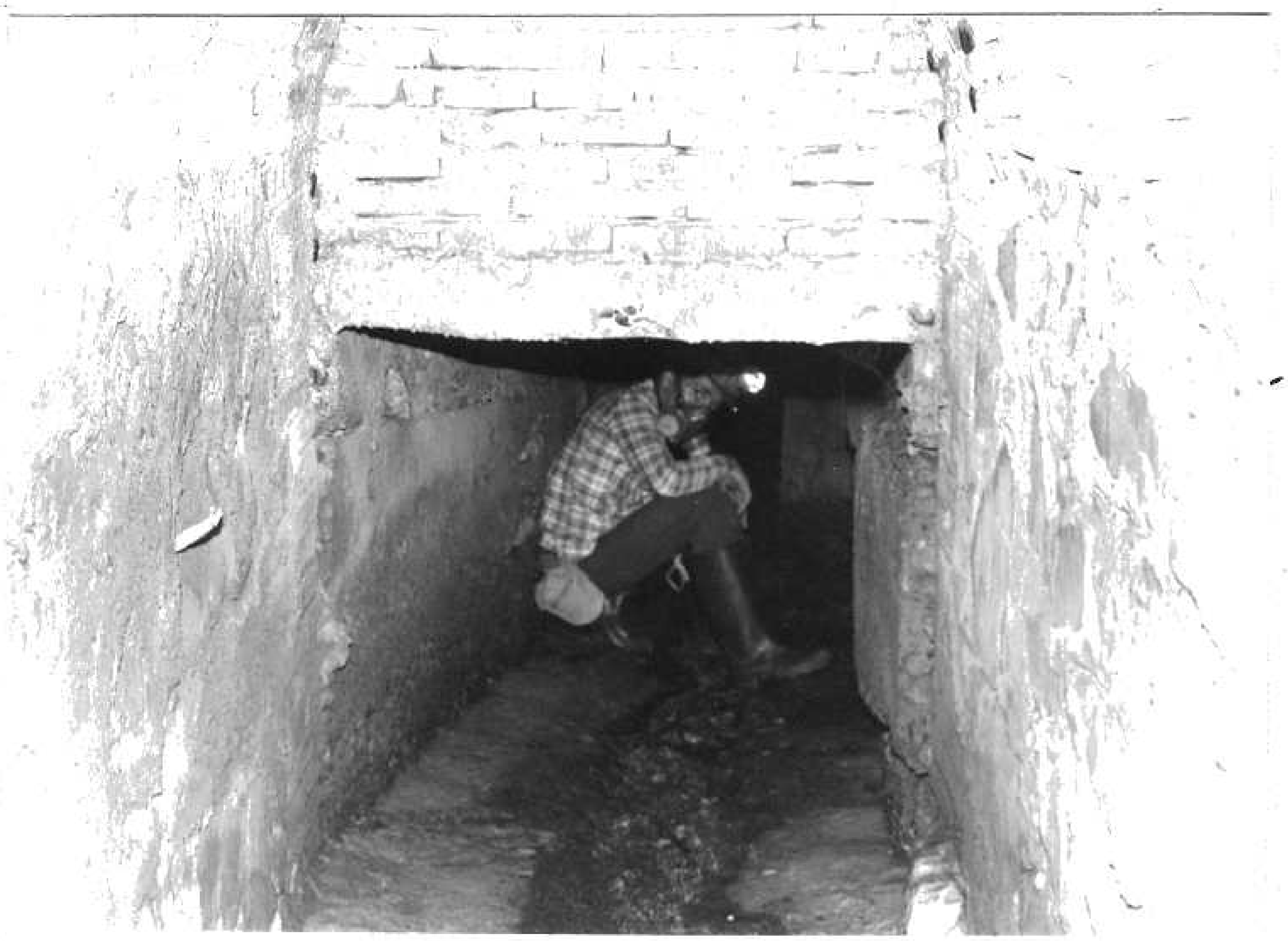
Vivoni-Acosta, Joffre, 1988

APPENDIX I:

PHOTOGRAPHS

PHOTO NO.:	SUBJECT:	LOCATION: DRAWING NO.
1	Railroad culvert	2
2	Square crossection	2
3	Constriction: projecting column	3
4	Calle Tetuán culvert	4
5	Corbelled brick drain on Calle Esperanza culvert	6
6	Repaired vault and removed floor	8
7	Culvert under Calle Luna for tributary stream from north	9
8	Confluence chamber	9
9	Abandoned vaulted brick branch (for storm or sewer inlet)	11
10	Vaulted brick branches discharging raw sewage	11
11	Abandoned stone-capped branch	12
12	Segment under Farmacia Cooperativa	12
13	Calle Cruz bridge	12
14	Wall repairs and channel rocks	13
15	Construction discontinuity	14
16	Large channel rocks	14
17	Access opening (from surface)	15
18	Calle Alfonso XII culvert and confluence with Antongiorgi stream	19
19	Removed floor and substitute piping for Antongiorgi vaulted brick branch	19
20	Construction discontinuity	20
21	Calle Ramas culvert--crack on vault	21

①



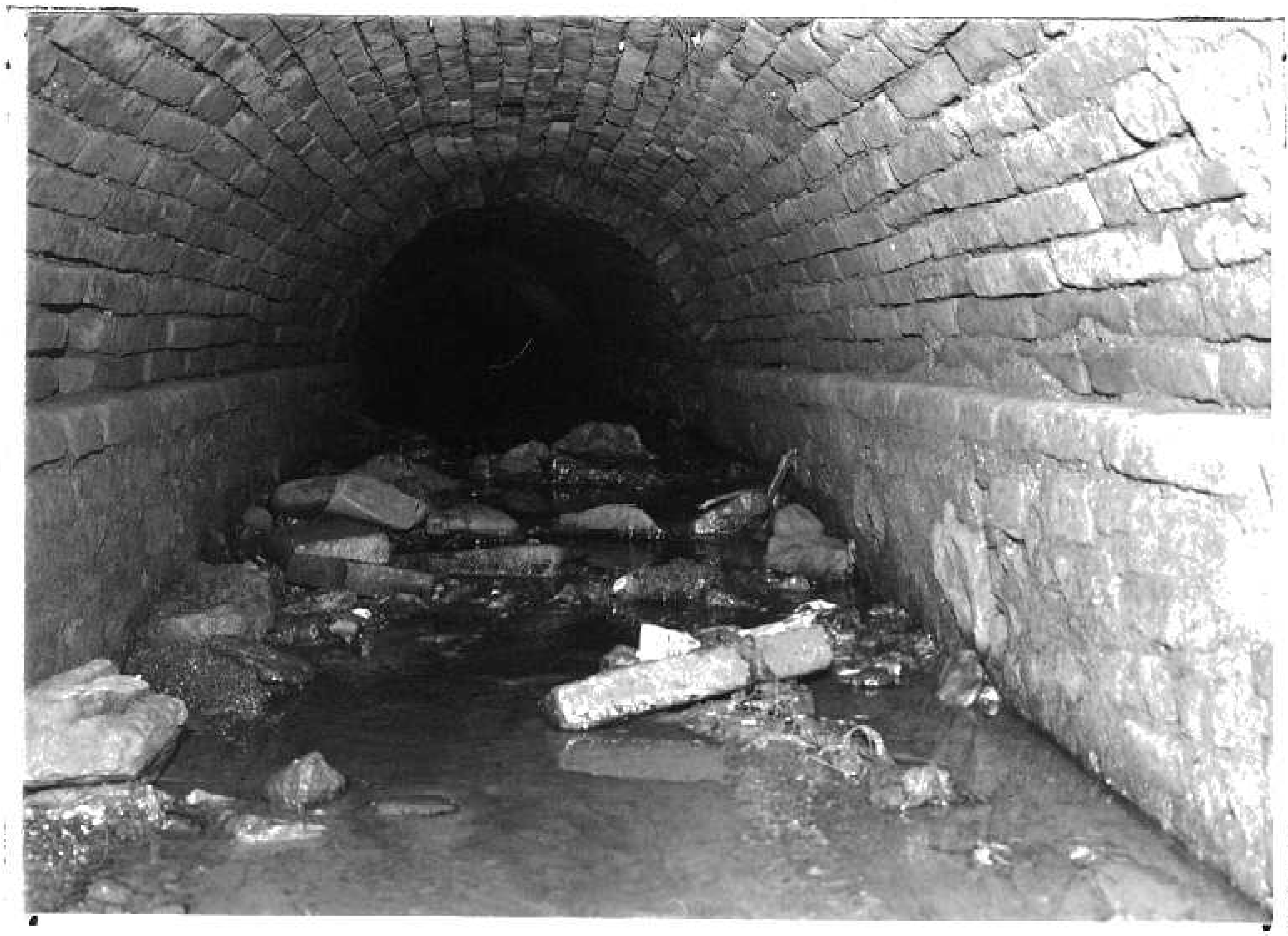
②

3

4

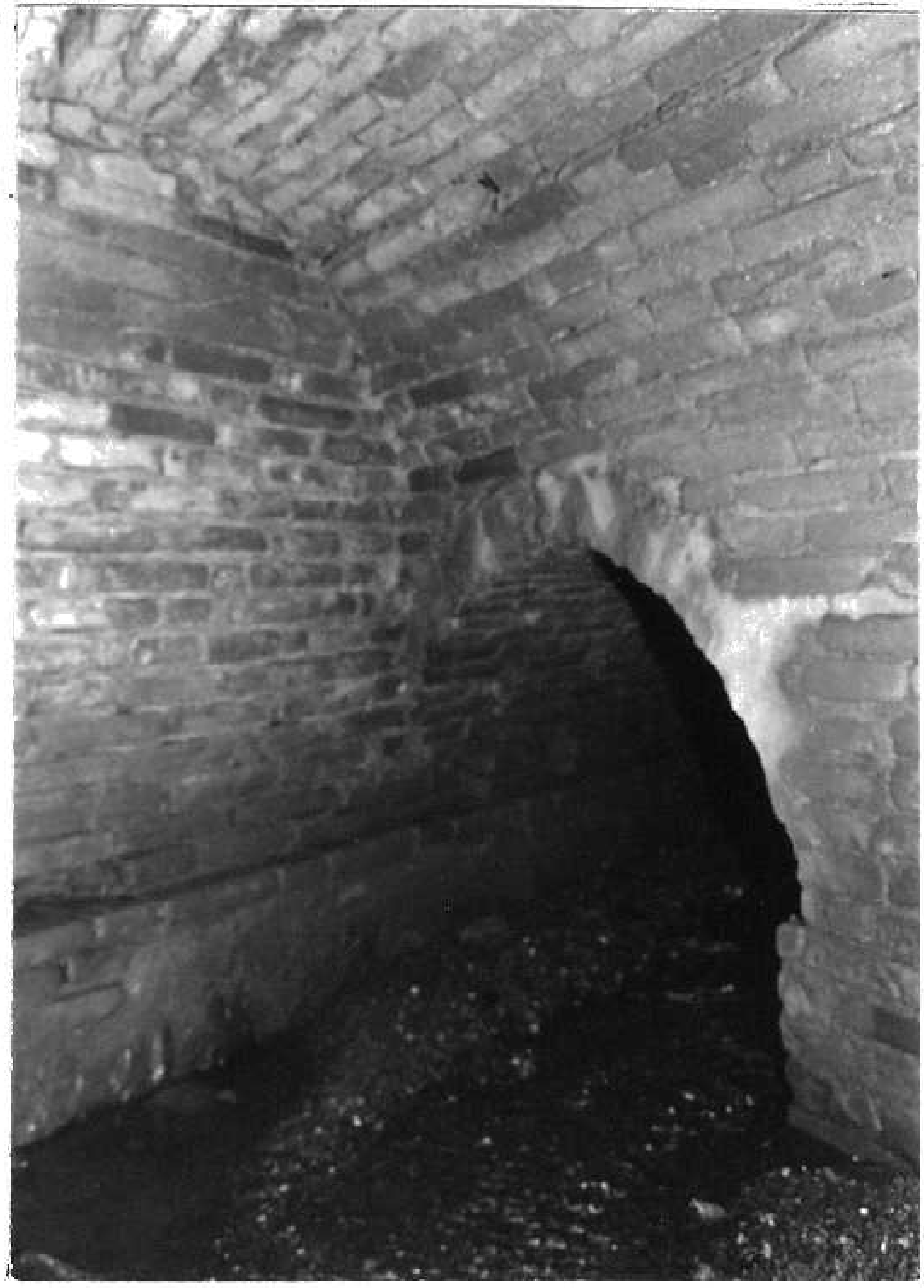
⑤

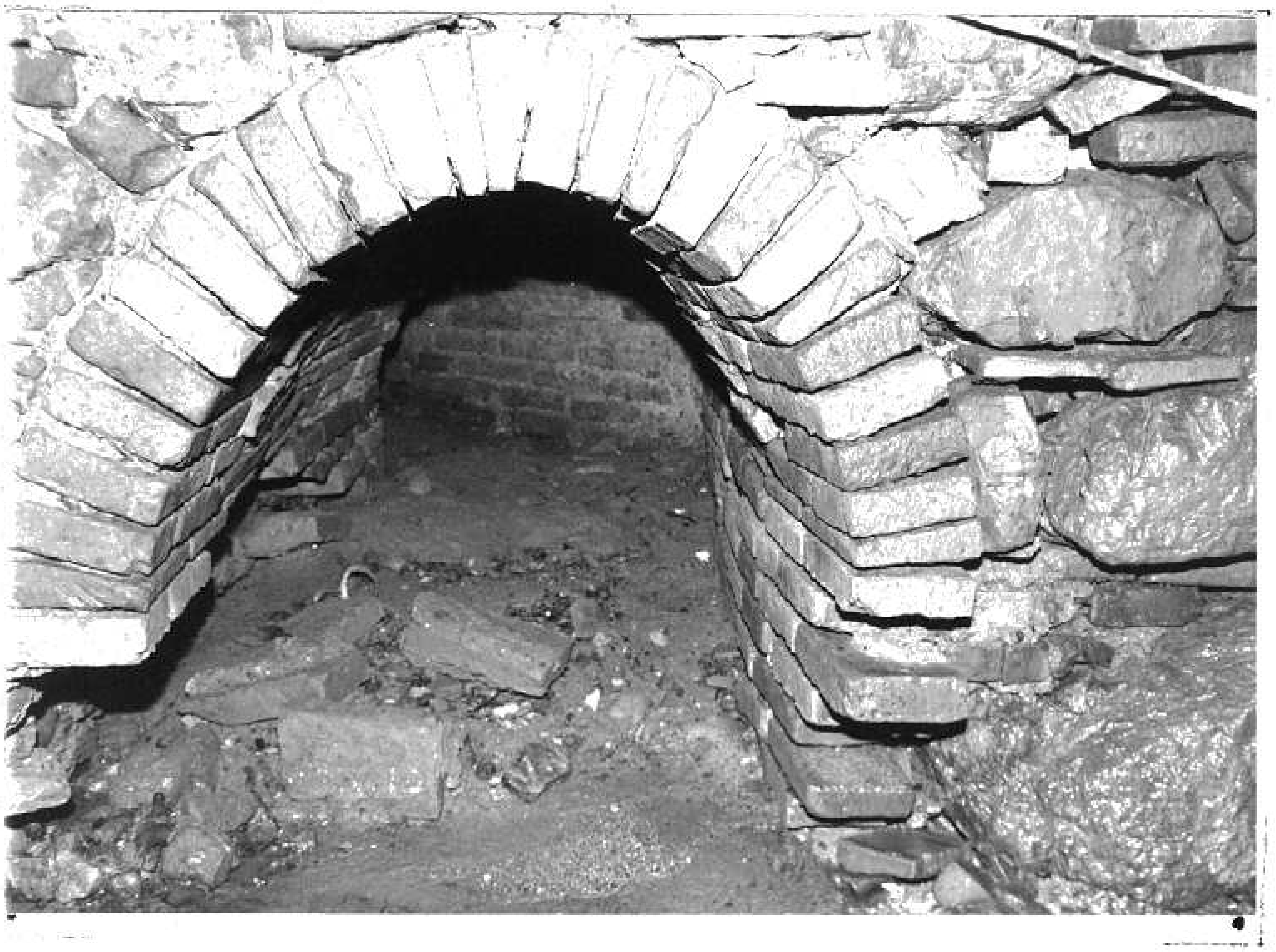
⑥



⑦

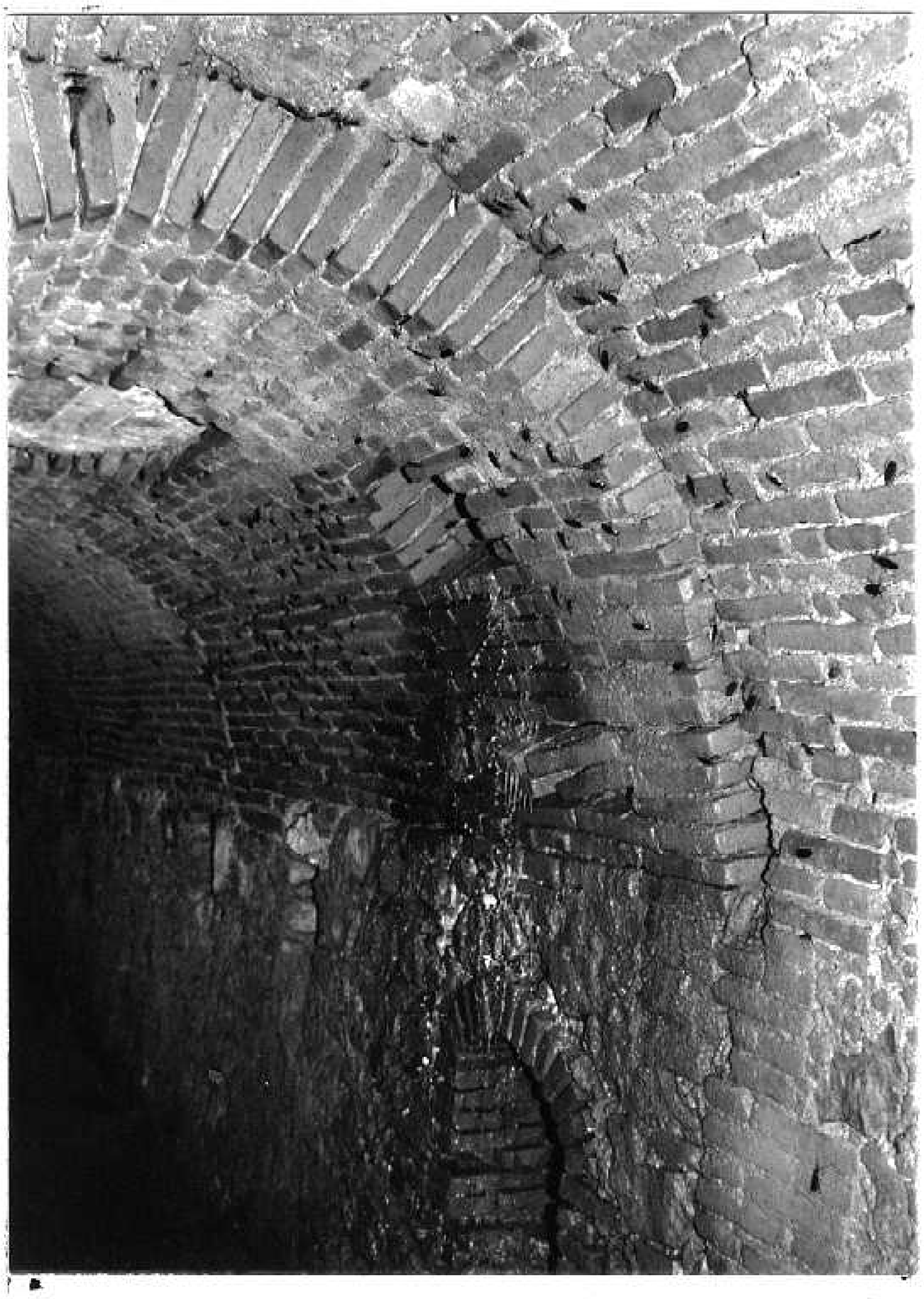
⑧

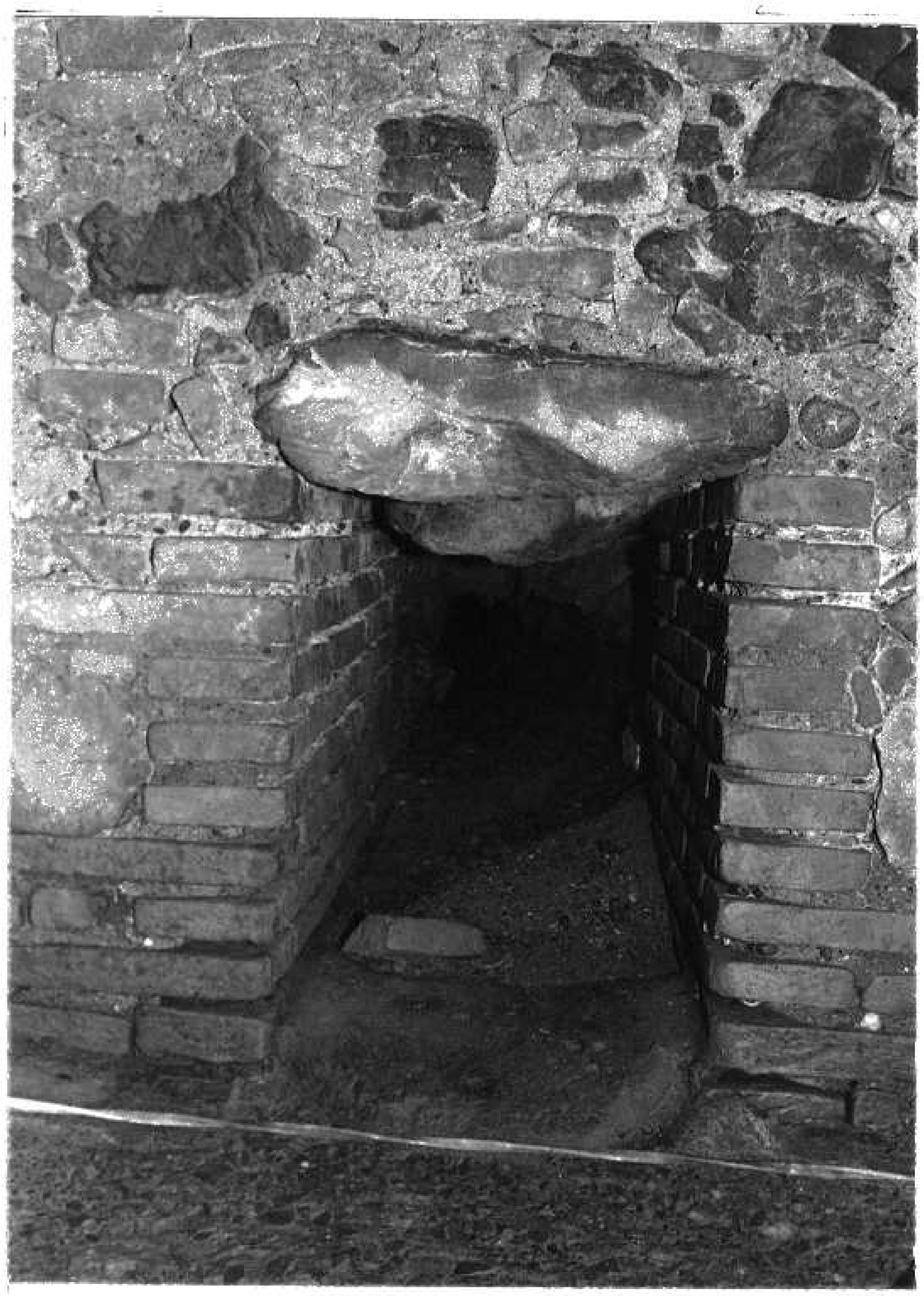




9

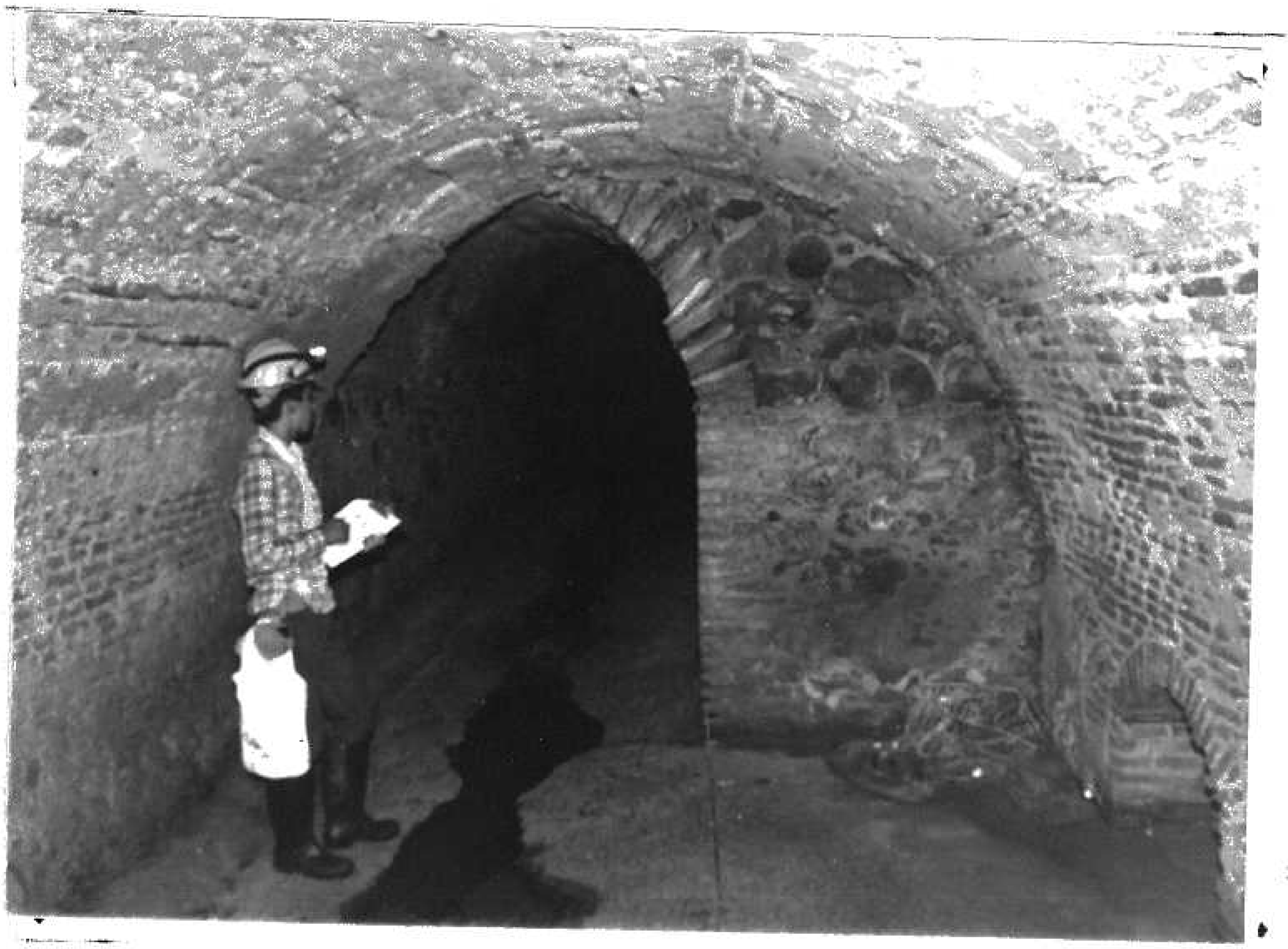
10

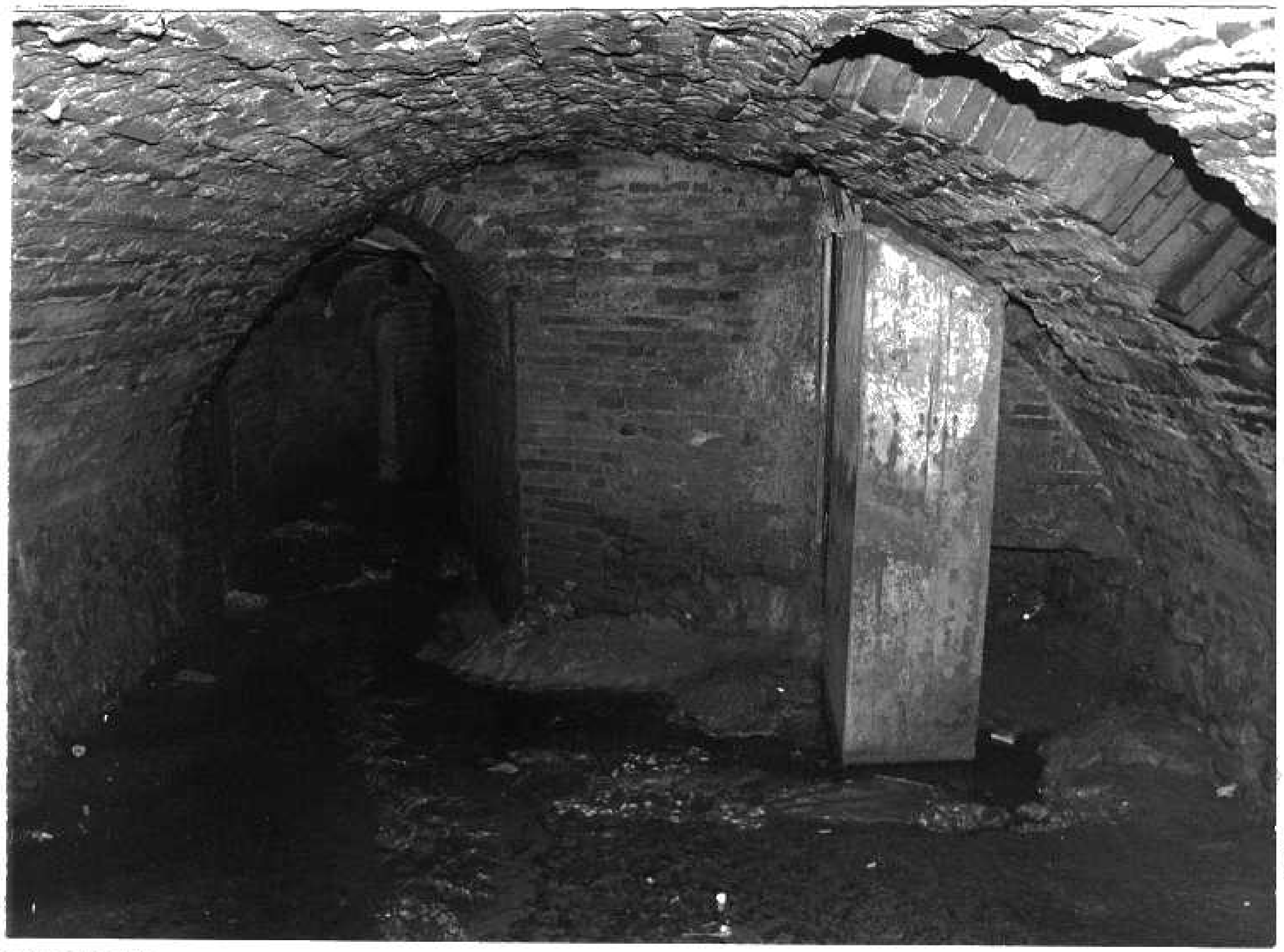




⑪

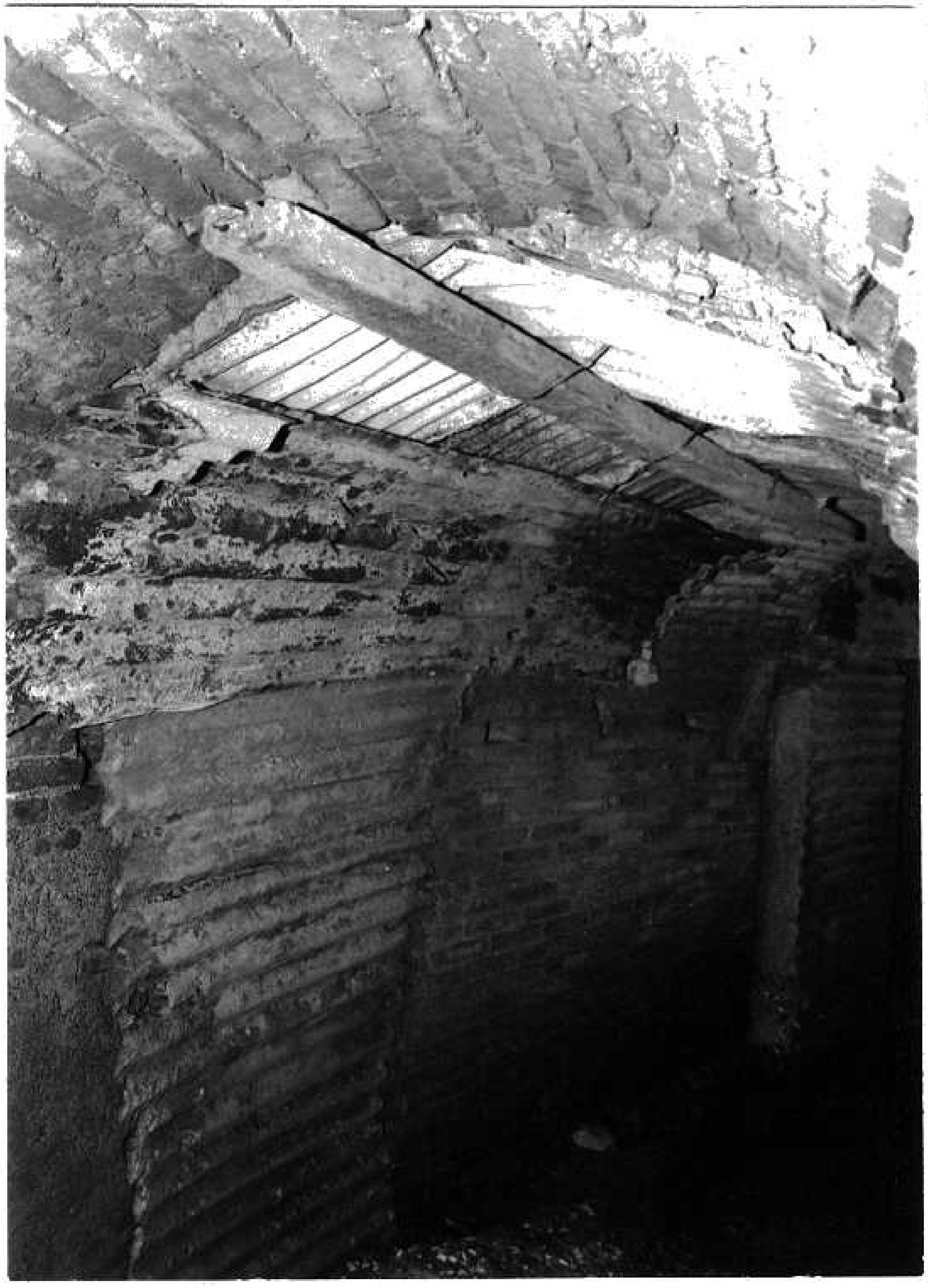
⑫

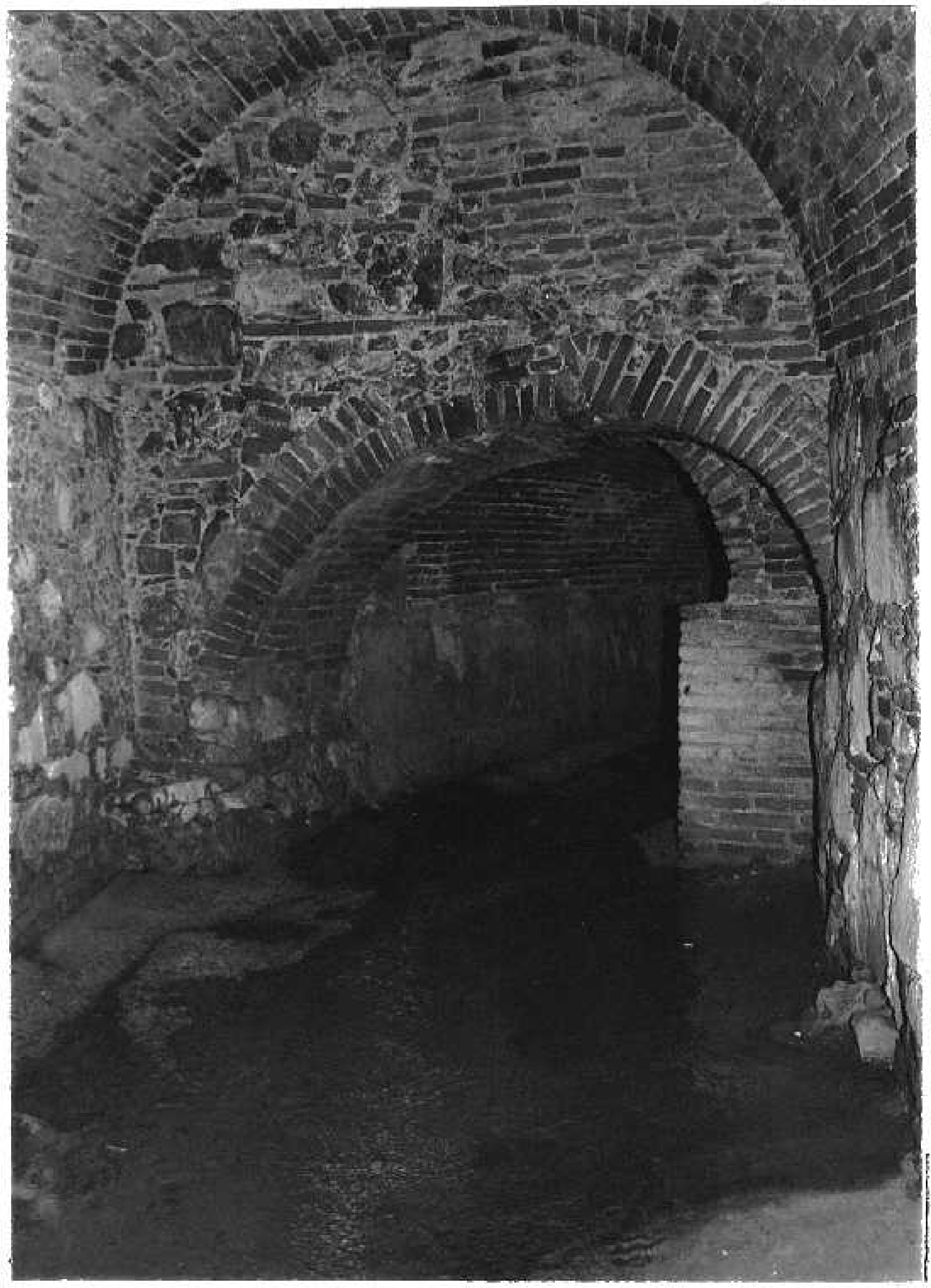




⑬

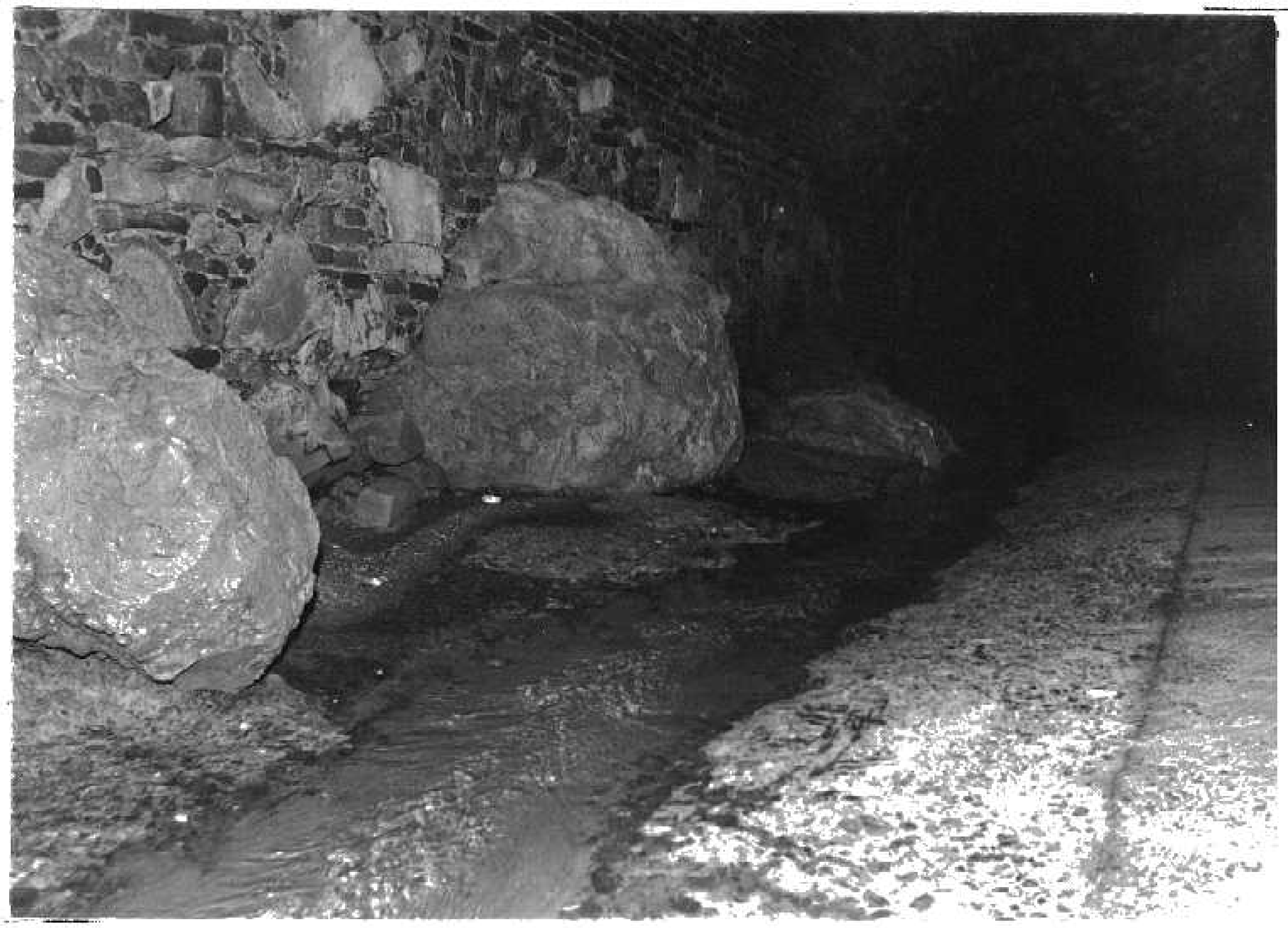
⑭



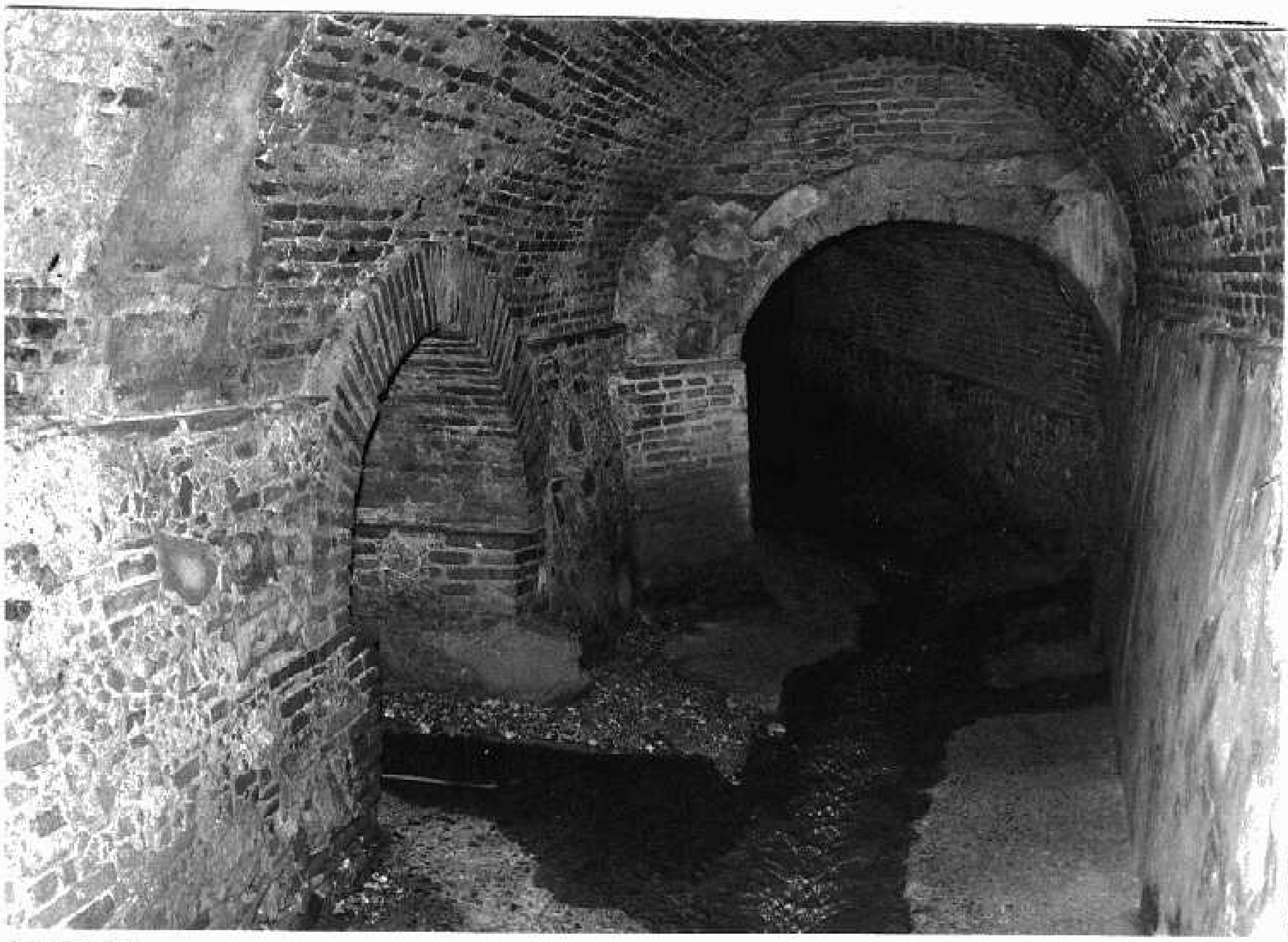


15

16

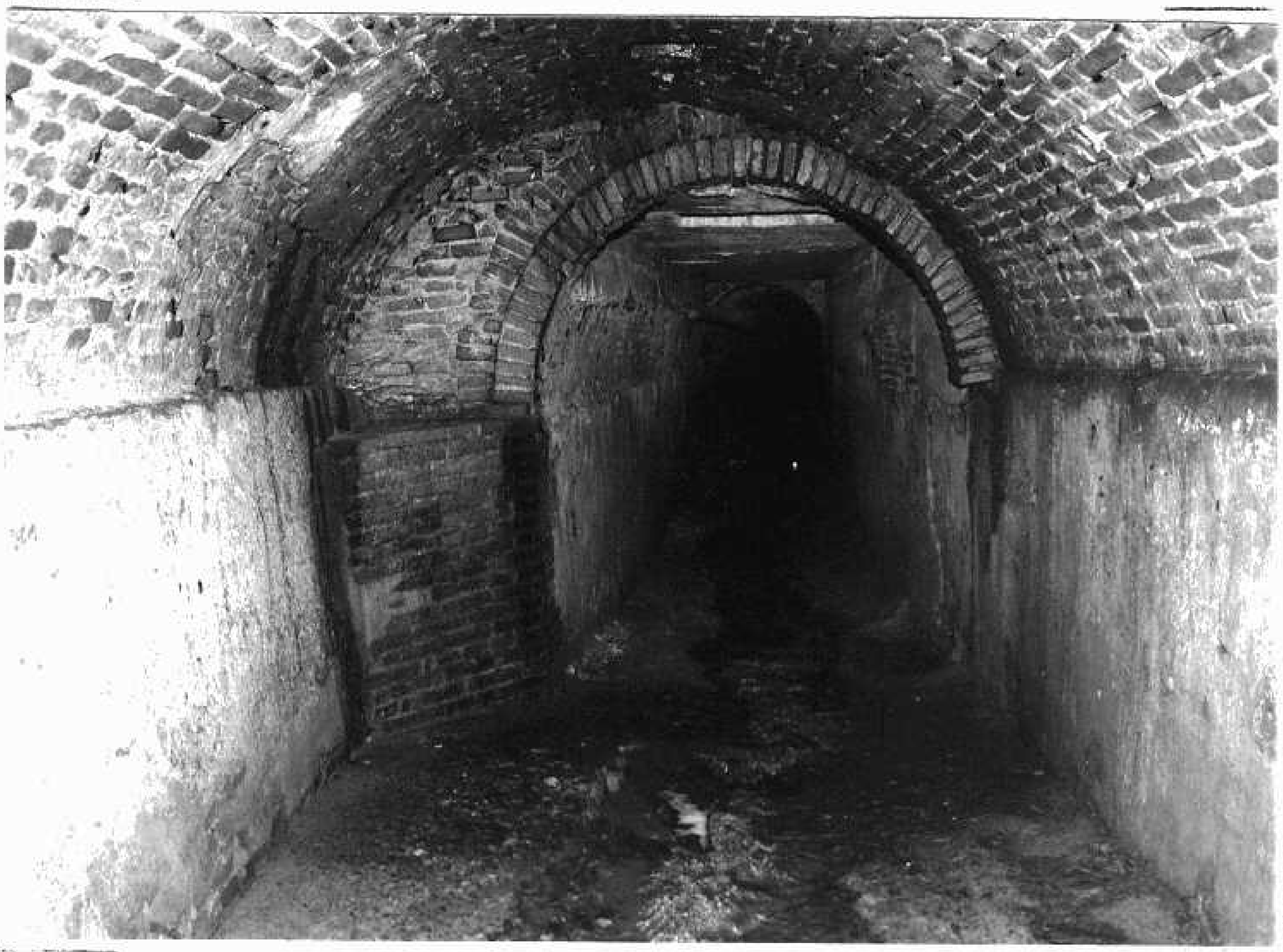


⑰

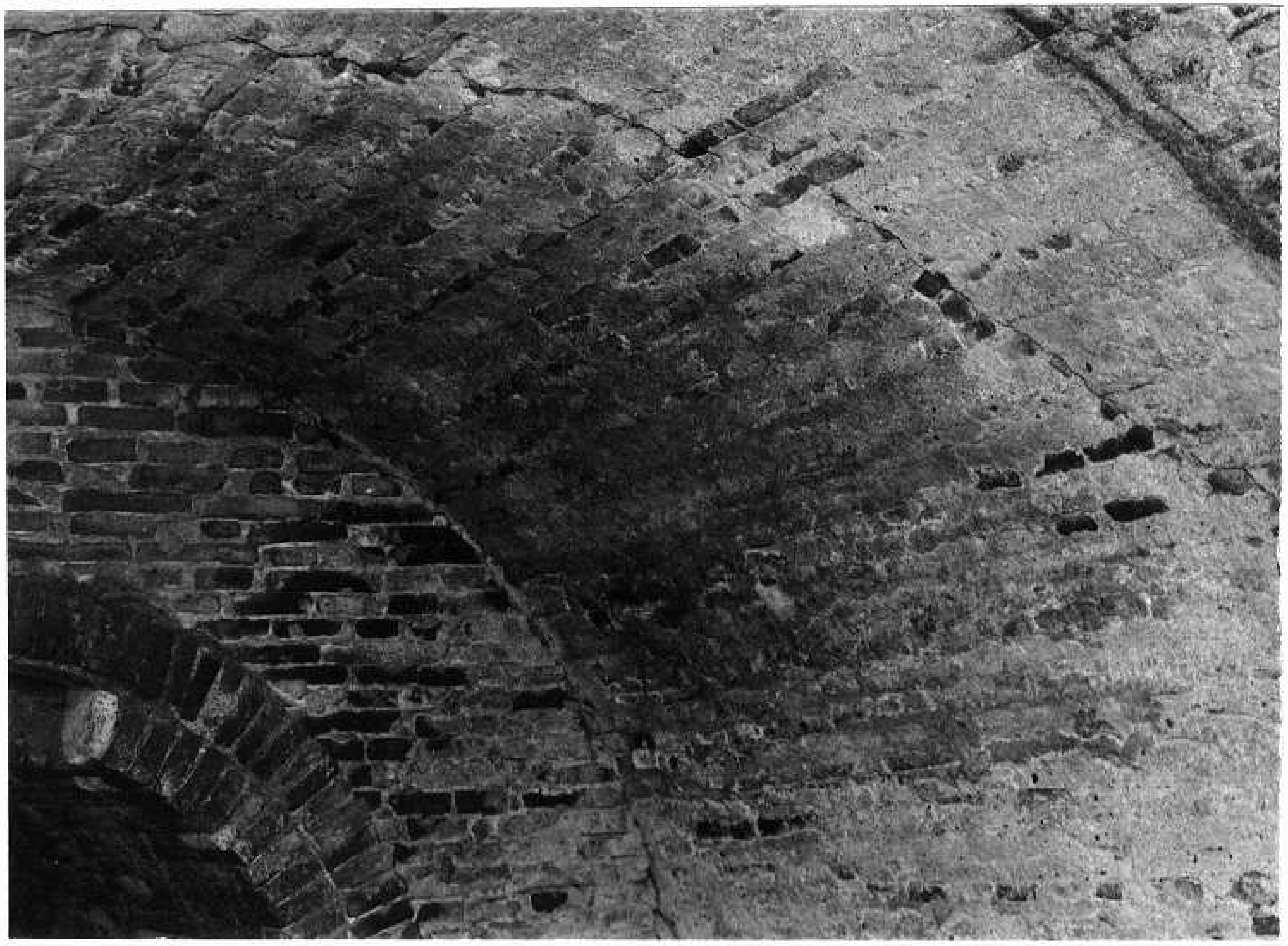


⑱

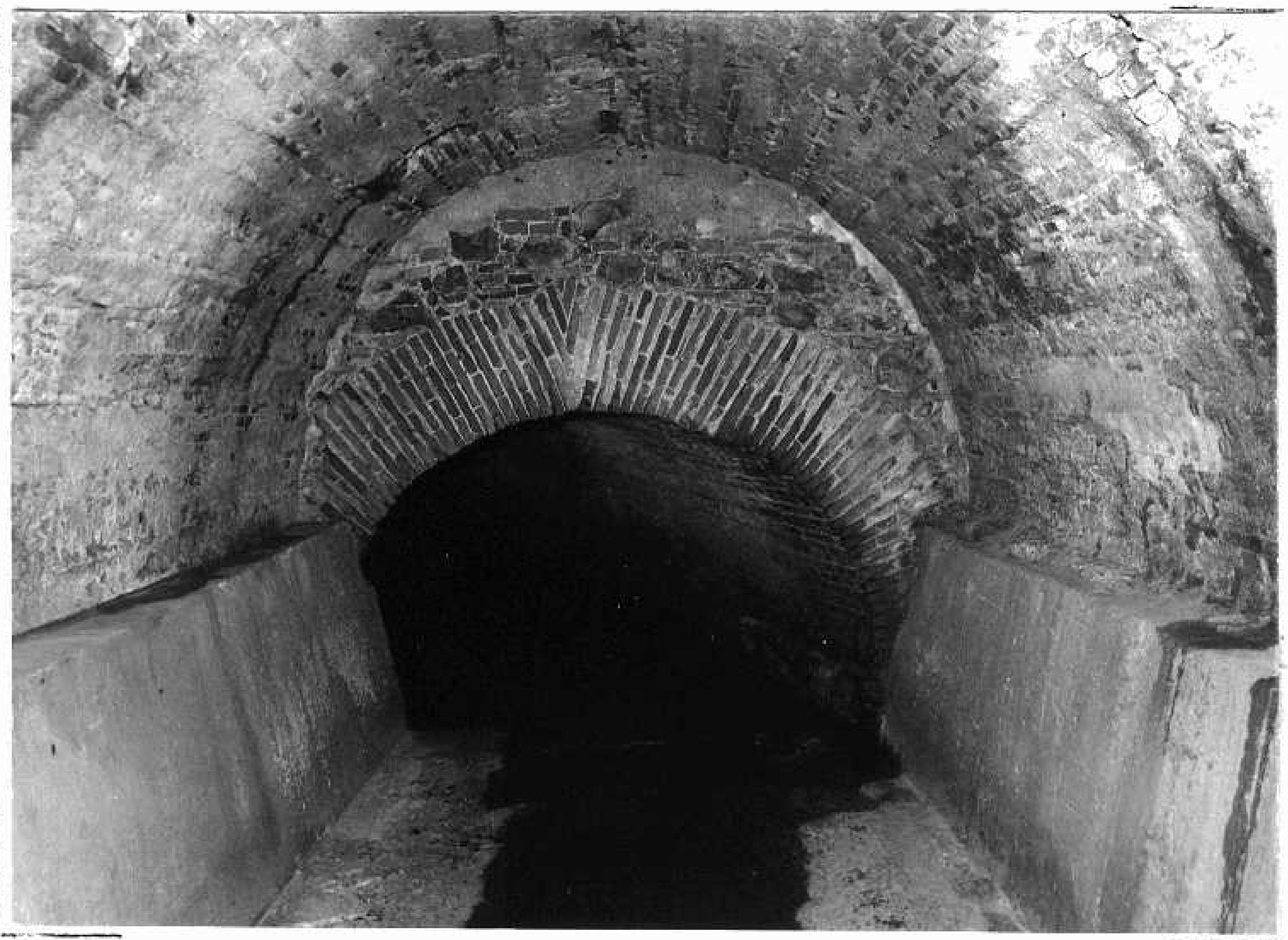
19



20



21



22

㉓

㉔

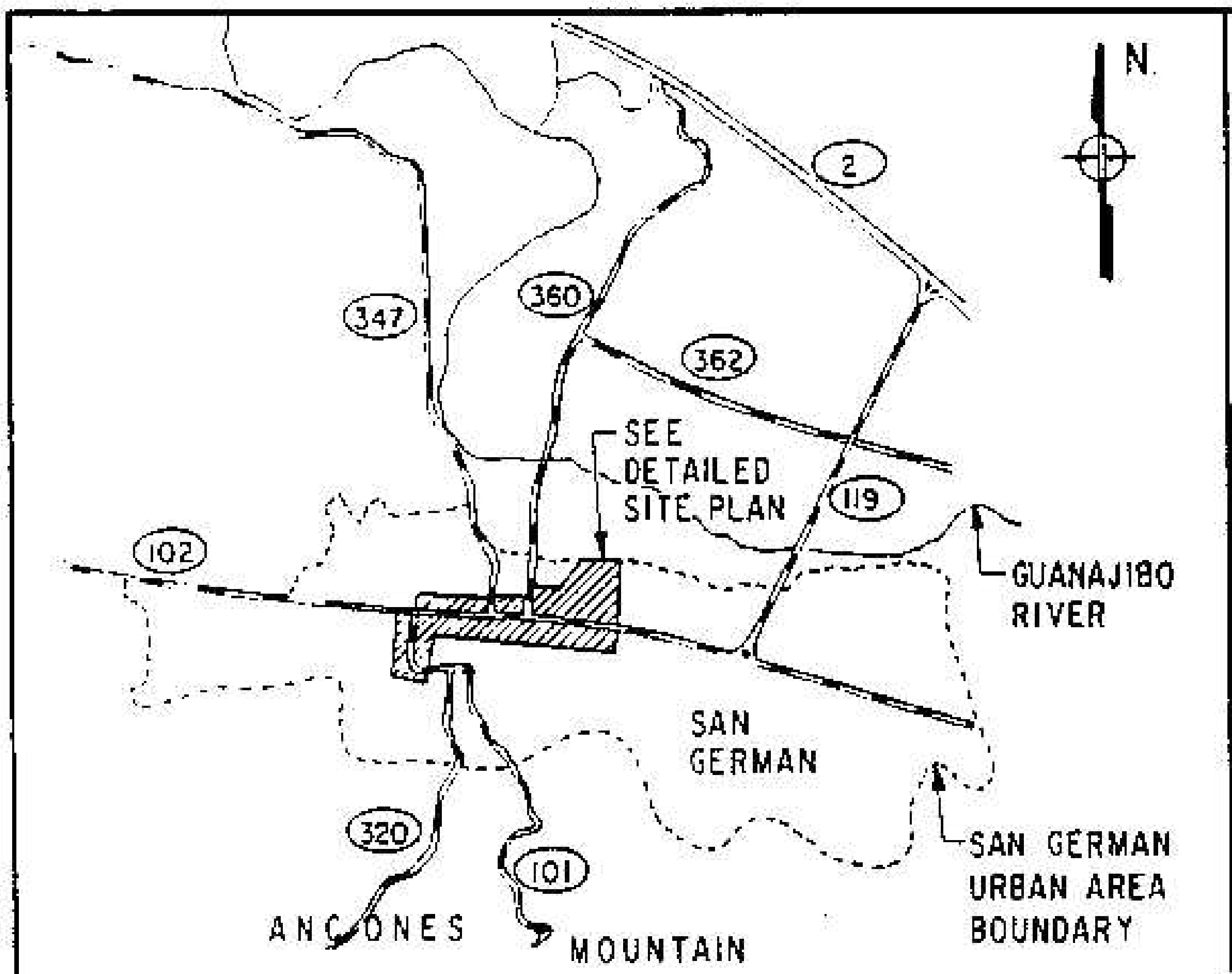
APPENDIX II:

DRAWINGS

SYMBOLS AND ABBREVIATIONS

(SIMBOLOS Y ABREVIATURAS)

⟿	DIRECTION OF PERMANENT WATER FLOW (DIRECCION DE FLUJO PERMANENTE DE AGUA)
C.I.	CAST IRON
(H.C.)	(HIERRO COLADO)
DIA.	DIAMETER (DIAMETRO)
CONC.	CONCRETE
(HORM.)	(HORMIGON)
S.W.	STORM WATER
(PL.)	(PLUVIAL)
CONST. DISC.	CONSTRUCTION DISCONTINUITY
(CAMBIO CONST.)	(CAMBIO EN CONSTRUCCION)
W.W.	WASTE WATER
(A.U.)	(AGUAS USADAS)
P.V.C.	POLYVINYL CHLORIDE PLASTIC PIPE (TUBERIA PLASTICO P.V.C.

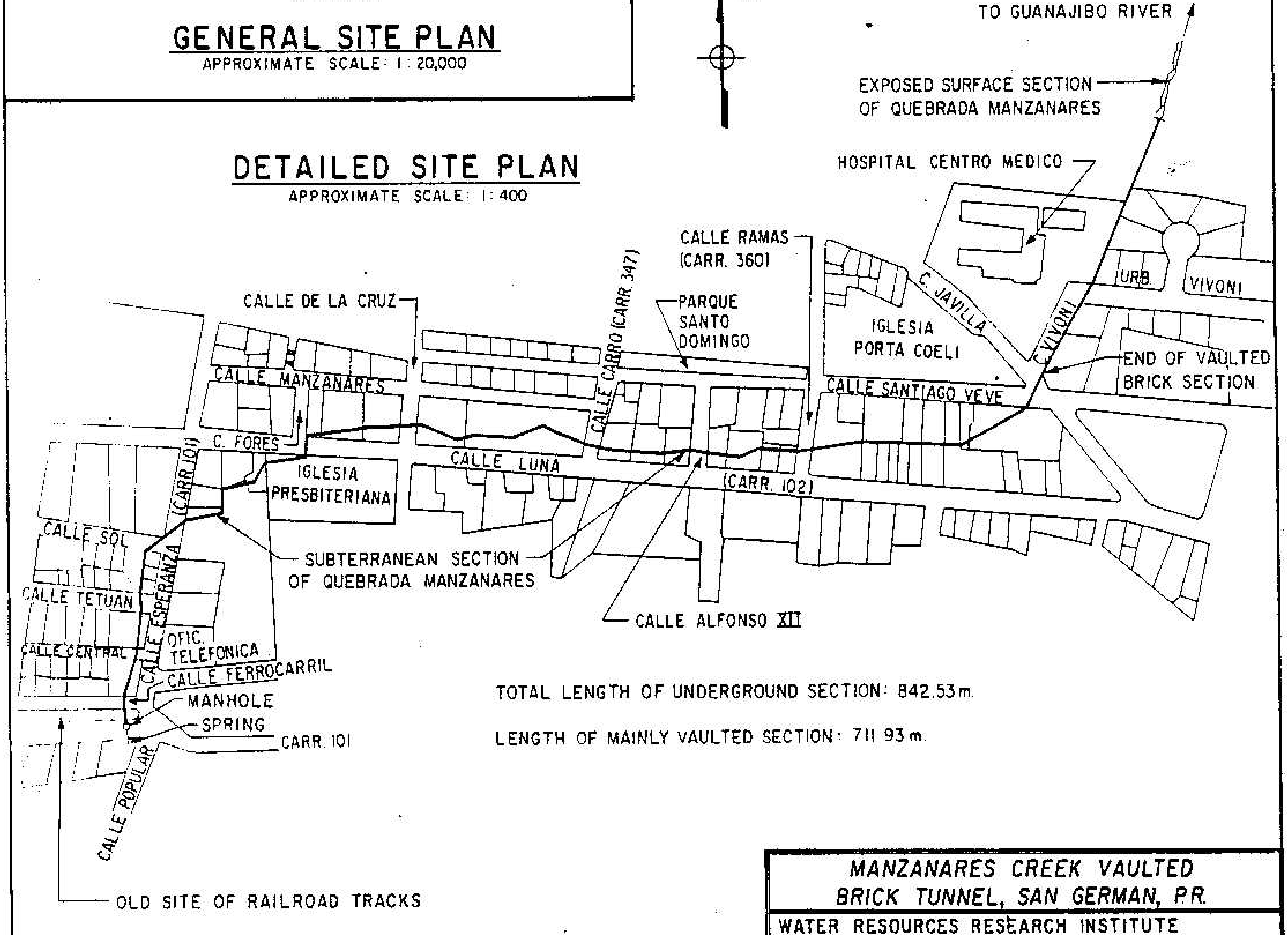


GENERAL SITE PLAN

APPROXIMATE SCALE: 1: 20,000

DETAILED SITE PLAN

APPROXIMATE SCALE: 1: 400



TOTAL LENGTH OF UNDERGROUND SECTION: 842.53 m.

LENGTH OF MAINLY VAULTED SECTION: 711 93 m.

NOTES

1. CROSSECTIONS DISTANCES MEASURED WITH 10 AND 20 FEET SURVEY TAPES. LONGITUDINAL DISTANCES MEASURED BY A 30 m. STEEL TAPE.
2. AZIMUTHS IN THE TUNNELS MEASURED BY A SUUNTO COMPASS WITH AN ACCURACY OF UP TO HALF DEGREE. VERTICAL ANGLES MEASURED WITH A SUUNTO CLINOMETER WITH AN ACCURACY OF ONE SIX TO ONE FOURTH OF A DEGREE.

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS: DR. LUIS F. PUMARADA
PROF. MIGUEL A. CRUZ AROCHO

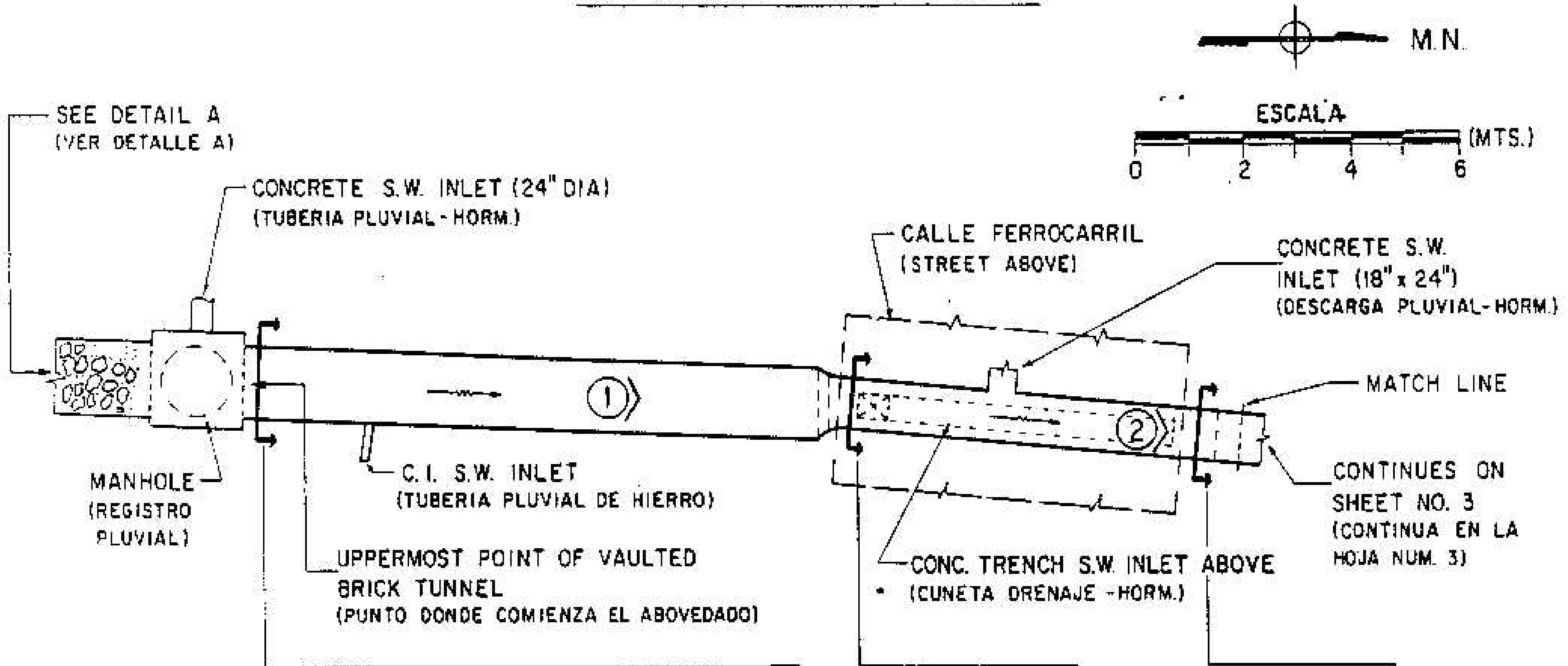
SURVEY ASSISTANTS: ANGEL NOEL COLON GUZMAN
RAFAEL B. TORRES LOPATEGUI

HISTORICAL RESEARCH: EDWIN ALBINO

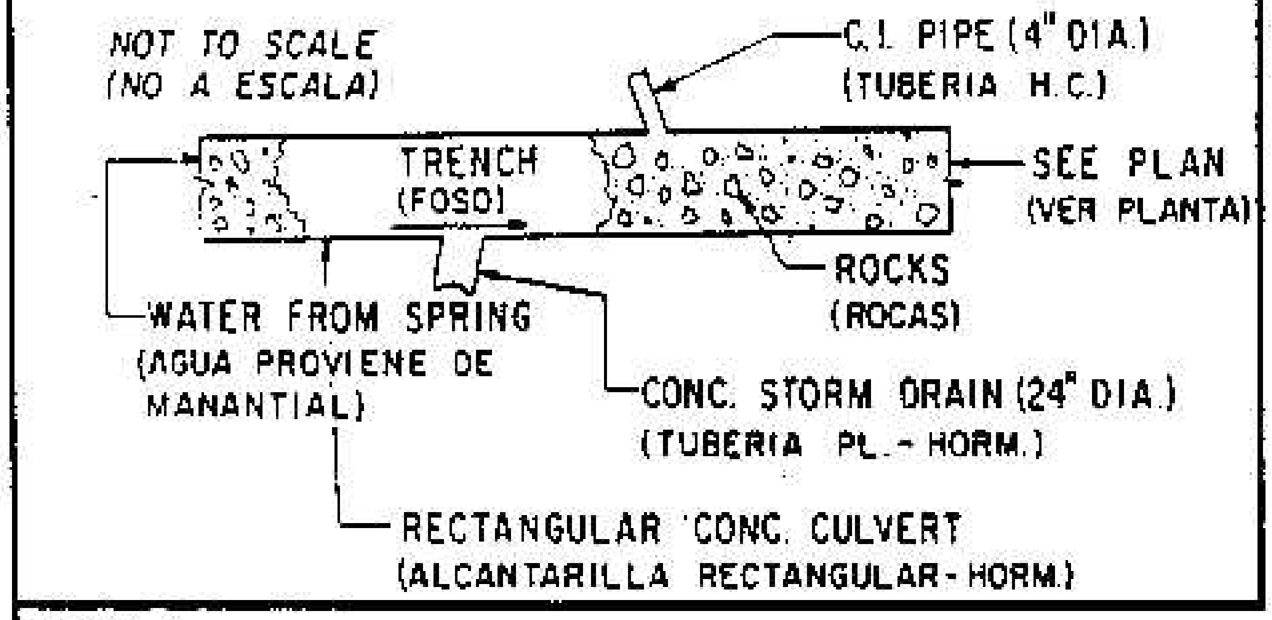
MAY-DECEMBER 1987

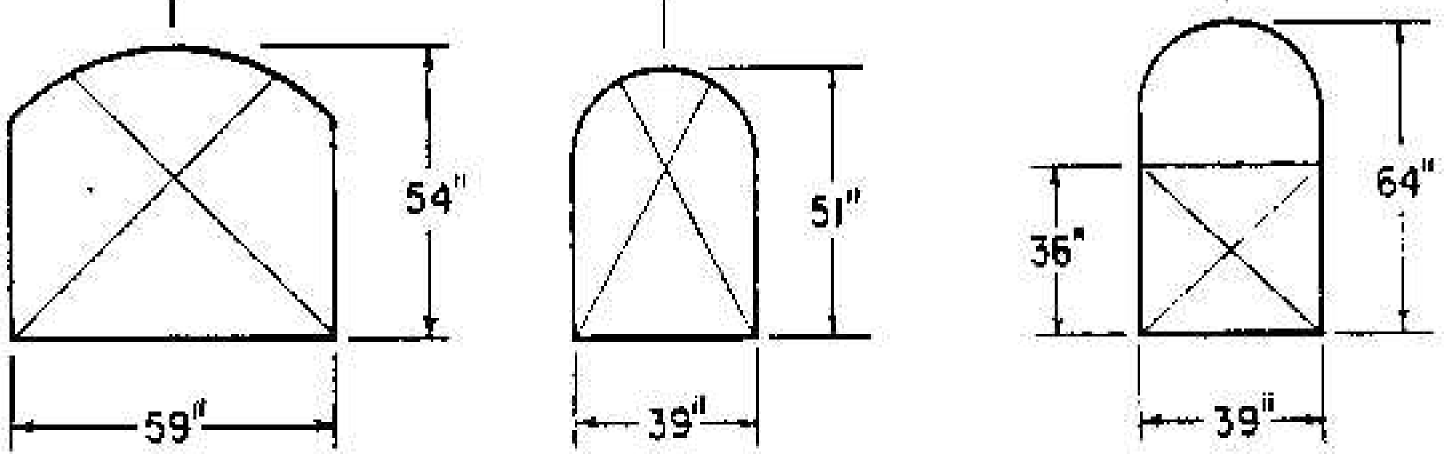
1/30

INTERIOR PLAN VIEW



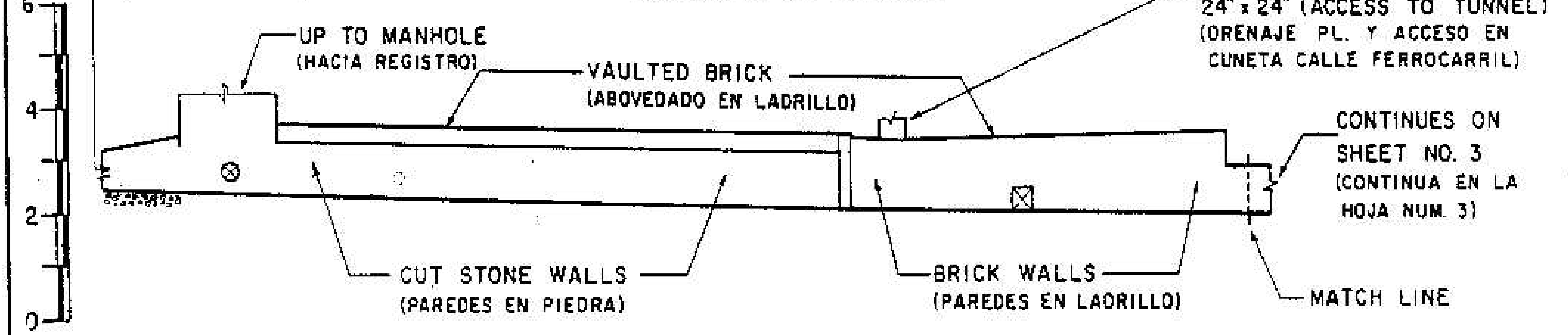
DETAIL - A: HEAD OF MANZANARES CREEK (PLAN VIEW)
(DETALLE - A: NACIMIENTO QUEBRADA MANZANARES (PLANTA)





SECTIONS
(DOUBLE PLAN VIEW SCALE)

INTERIOR PROFILE VIEW
(HORIZONTAL NOT TO SCALE)



NOTE: FLOORS MADE OF CONCRETE
(TODOS LOS PISOS EN HORMIGON)

⑤〉 LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED BRICK TUNNEL, SAN GERMAN, P.R.

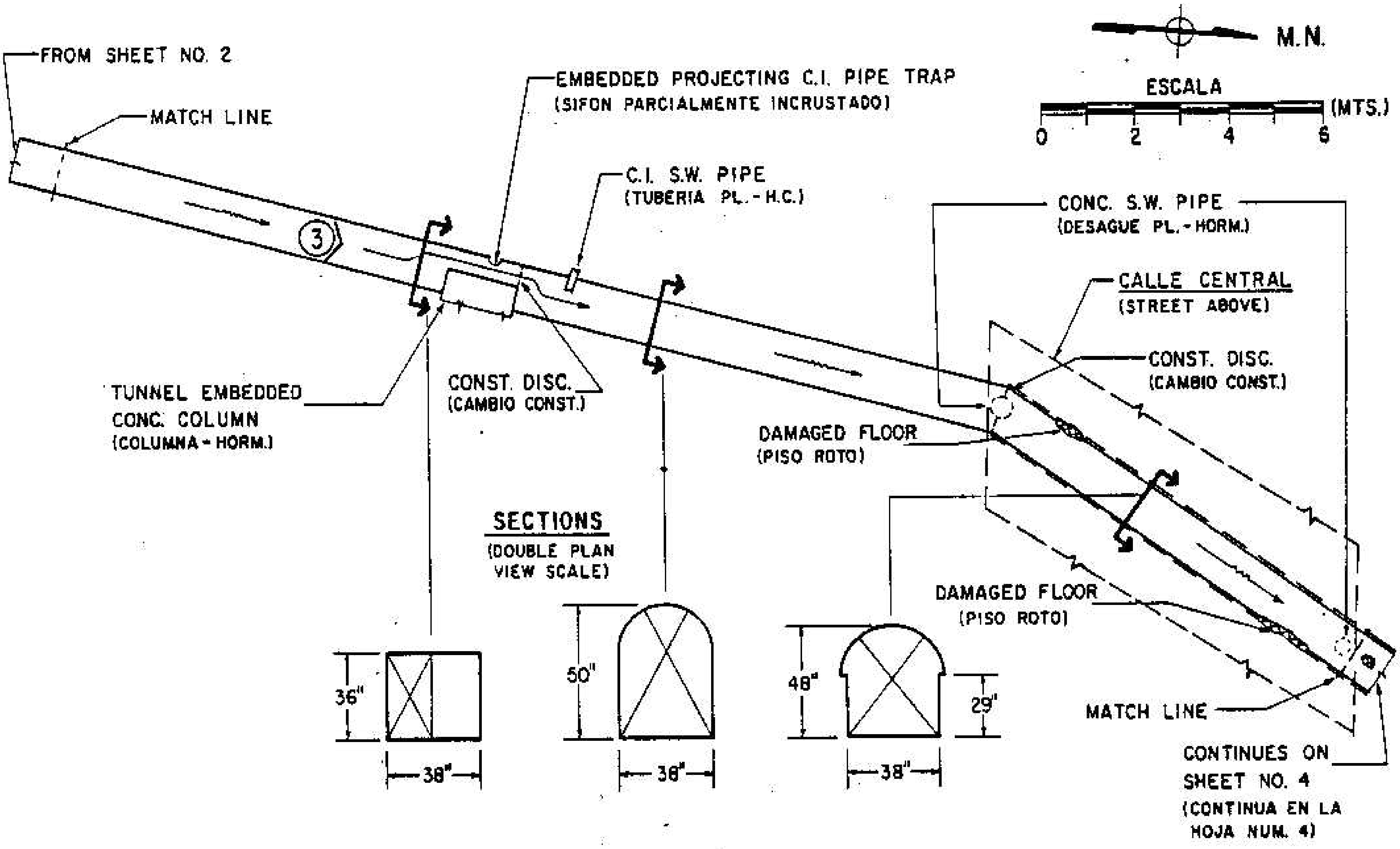
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

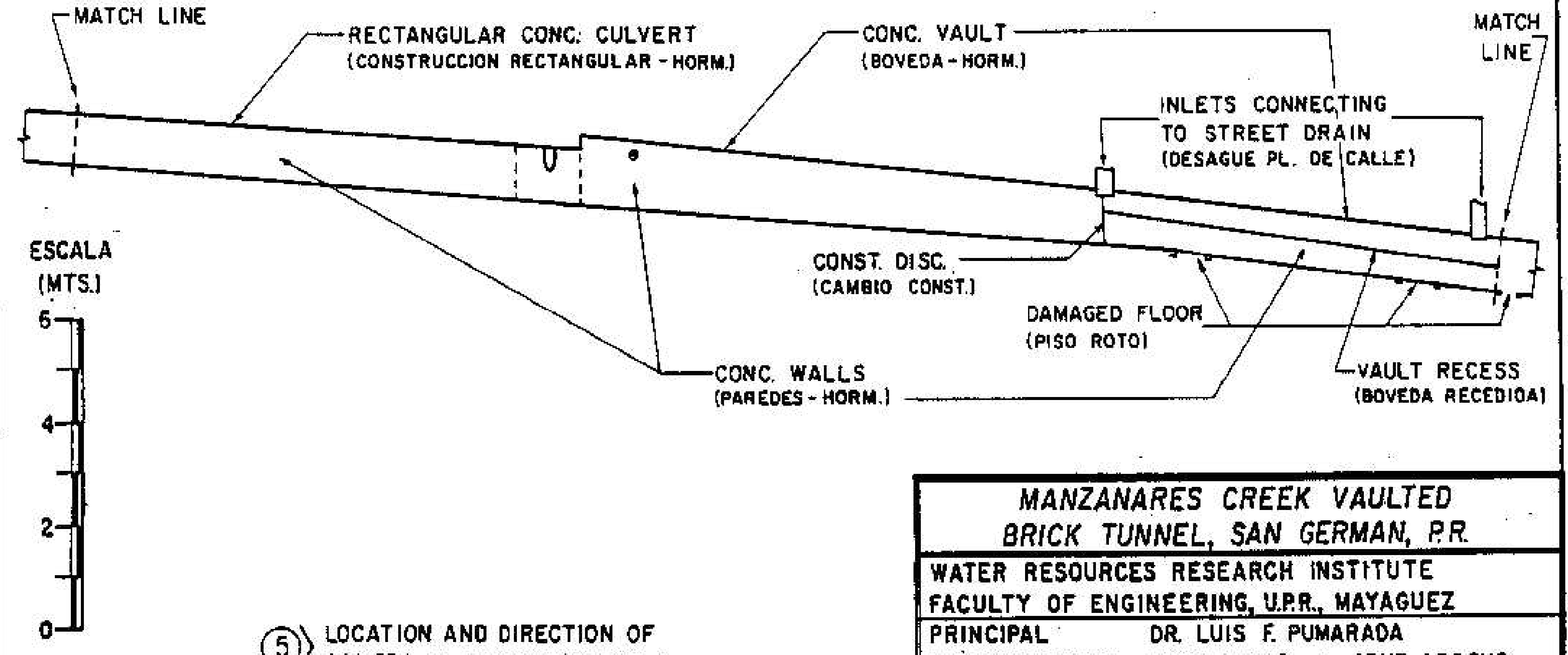
2/30

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

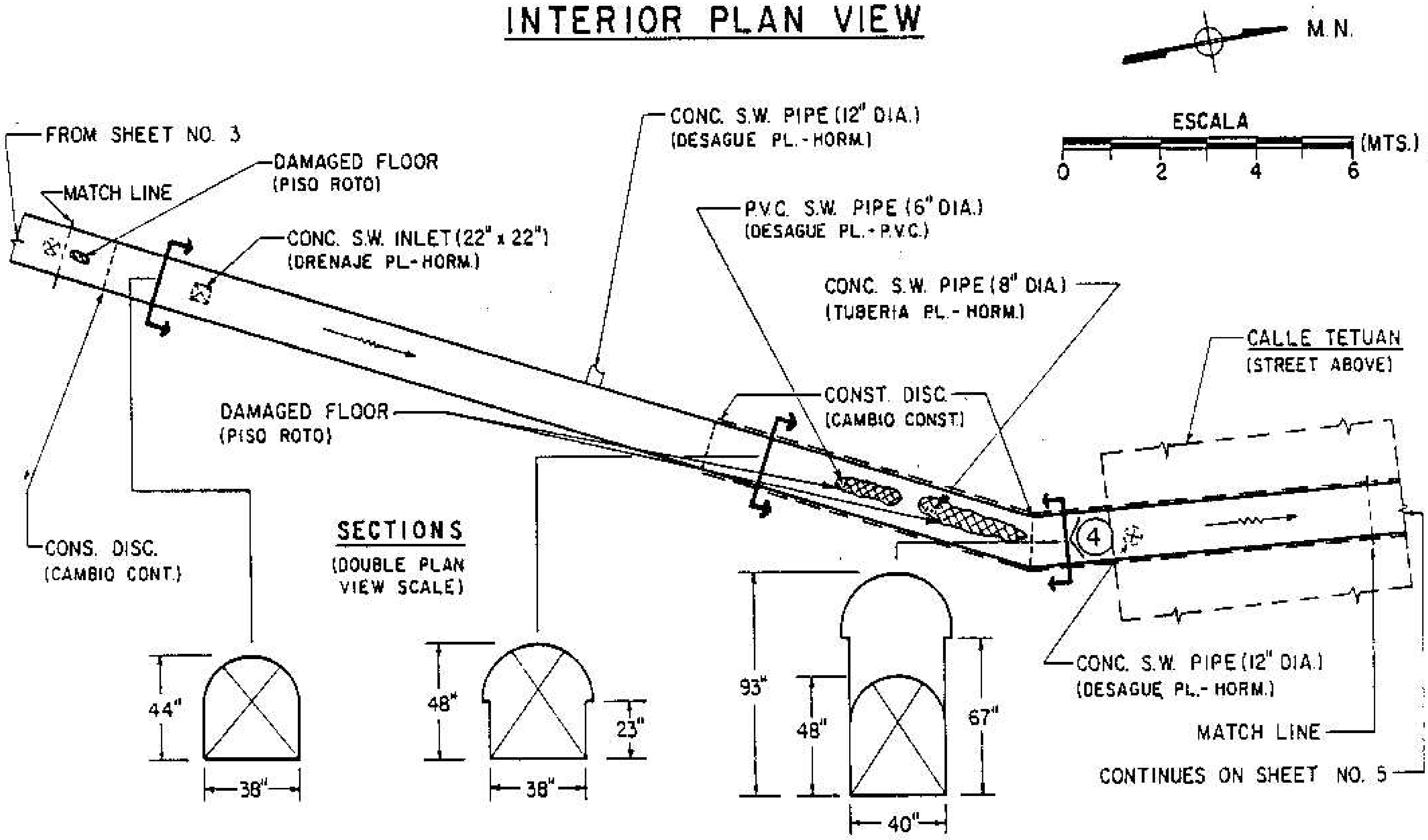
PRINCIPAL INVESTIGATORS: DR. LUIS F. PUMARADA
PROF. MIGUEL A. CRUZ AROCHO

SURVEY ASSISTANTS: ANGEL NOEL COLON GUZMAN
RAFAEL B. TORRES LOPATEGUI

HISTORICAL RESEARCH: EDWIN ALBINO

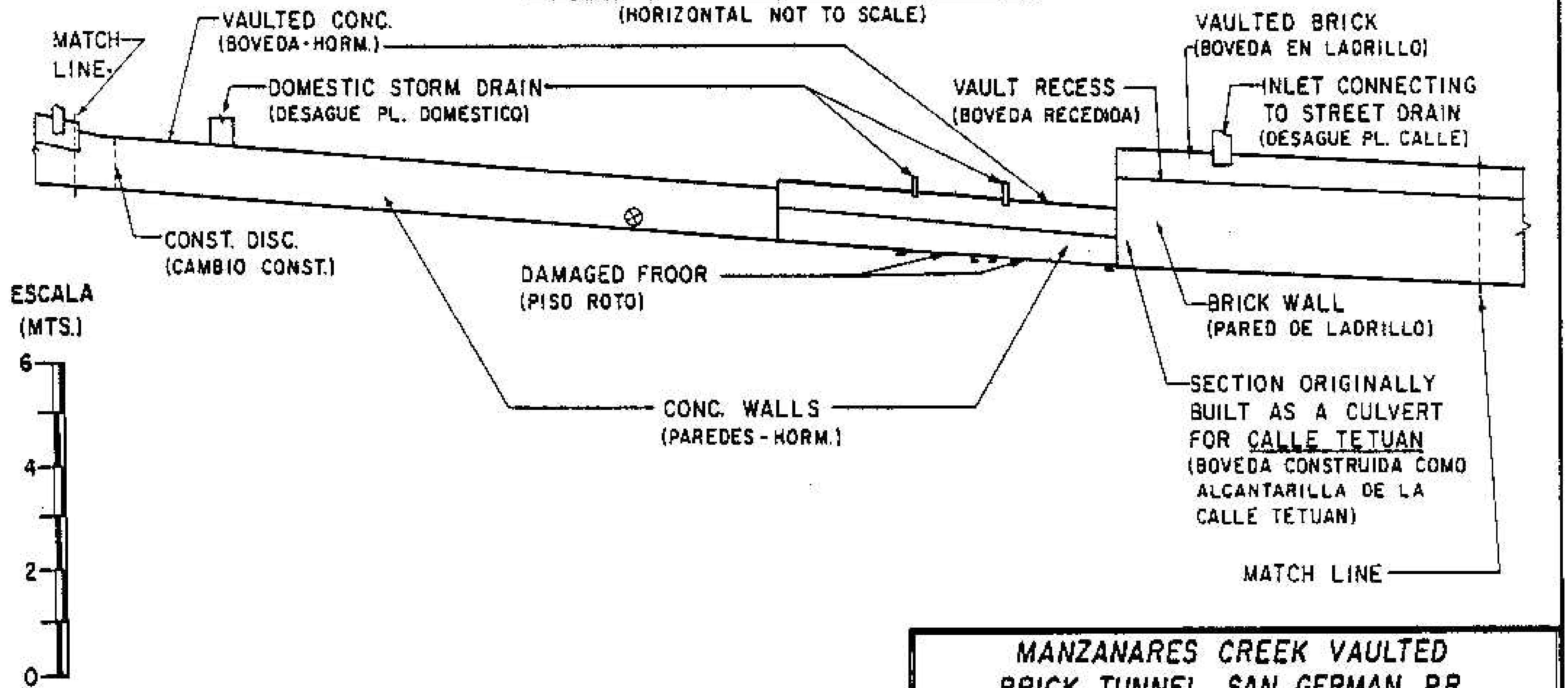
MAY-DECEMBER 1987

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED BRICK TUNNEL, SAN GERMAN, P.R.

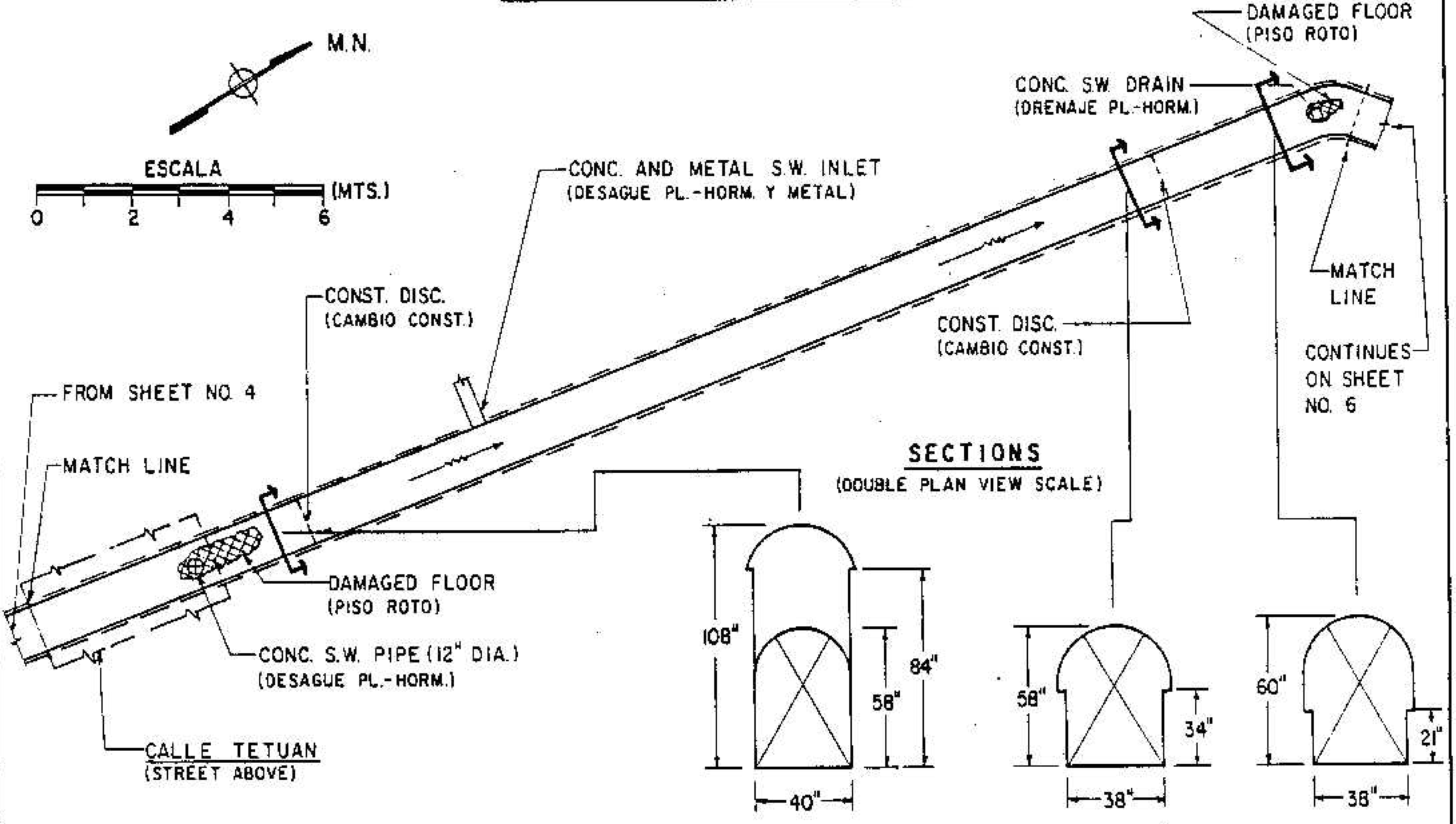
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

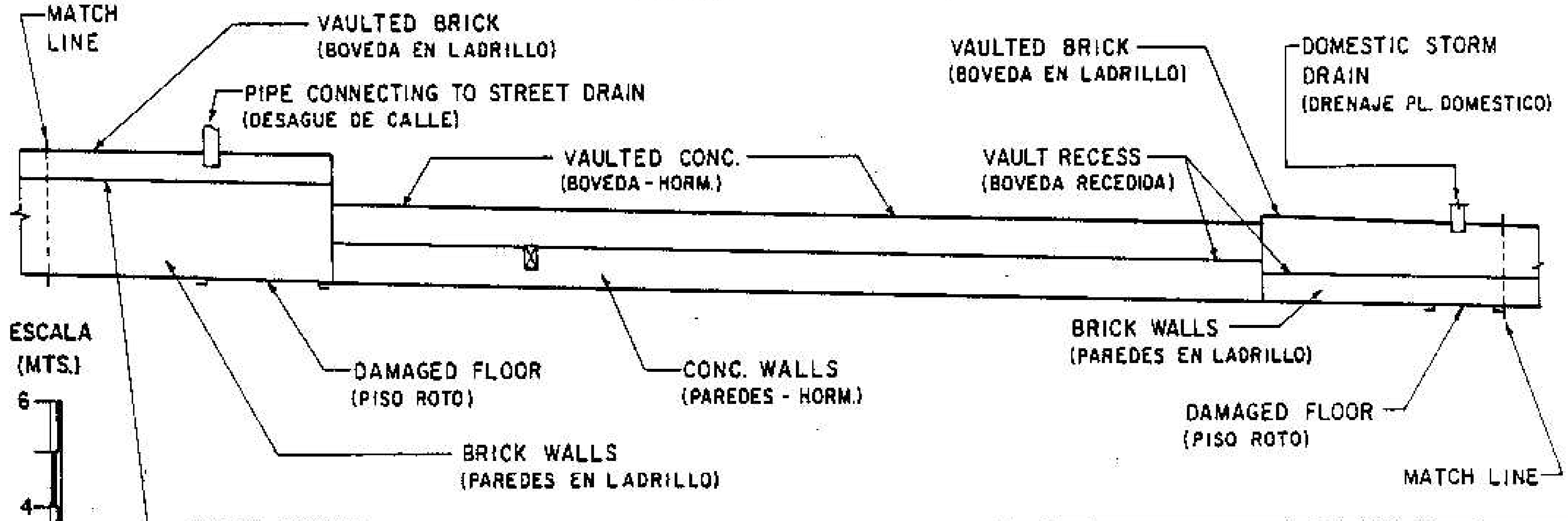
4/30

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

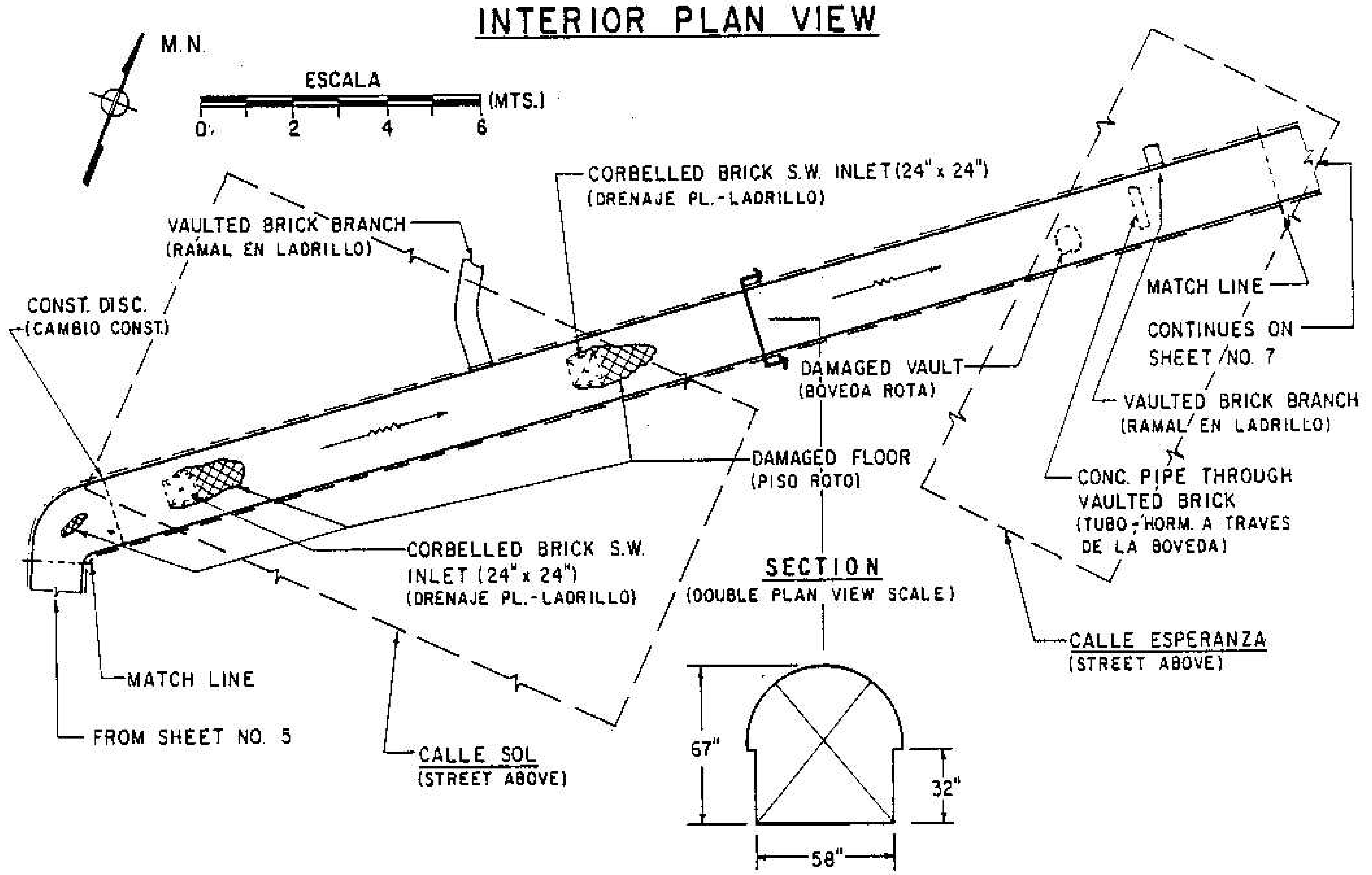
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

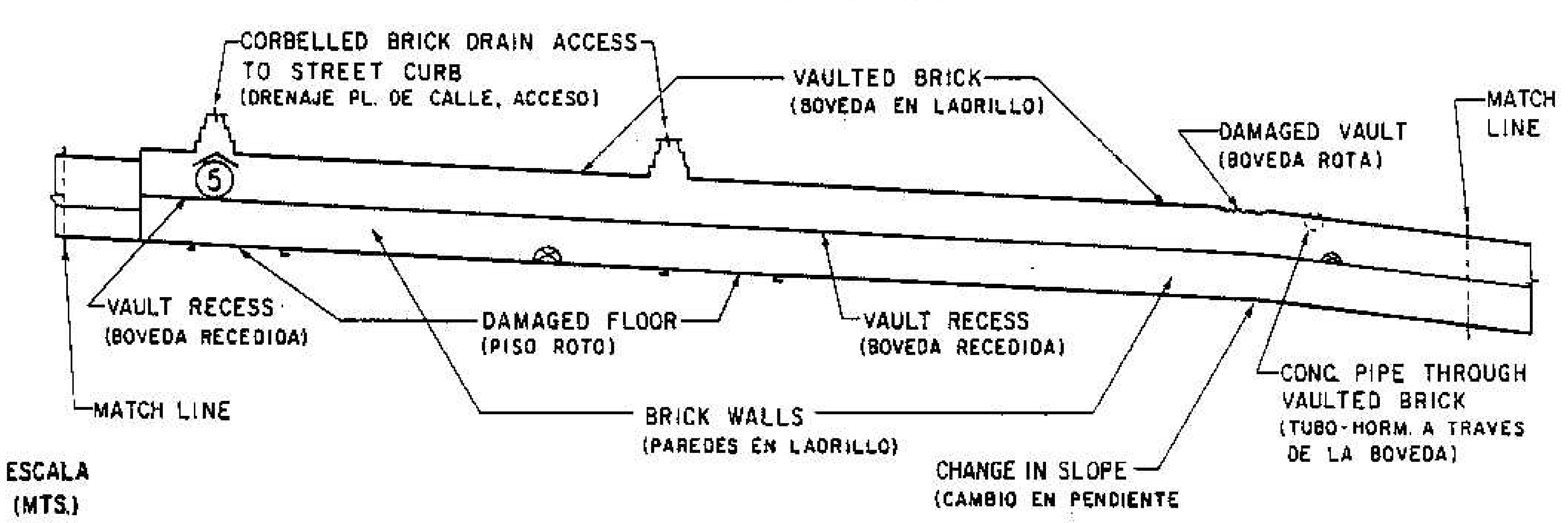
5/30

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



AVERAGE SLOPES:
(PENDIENTES PROMEDIO)

-5% UNDER CALLE SOL

-11% UNDER CALLE ESPERANZA

⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED BRICK TUNNEL, SAN GERMAN, P.R.

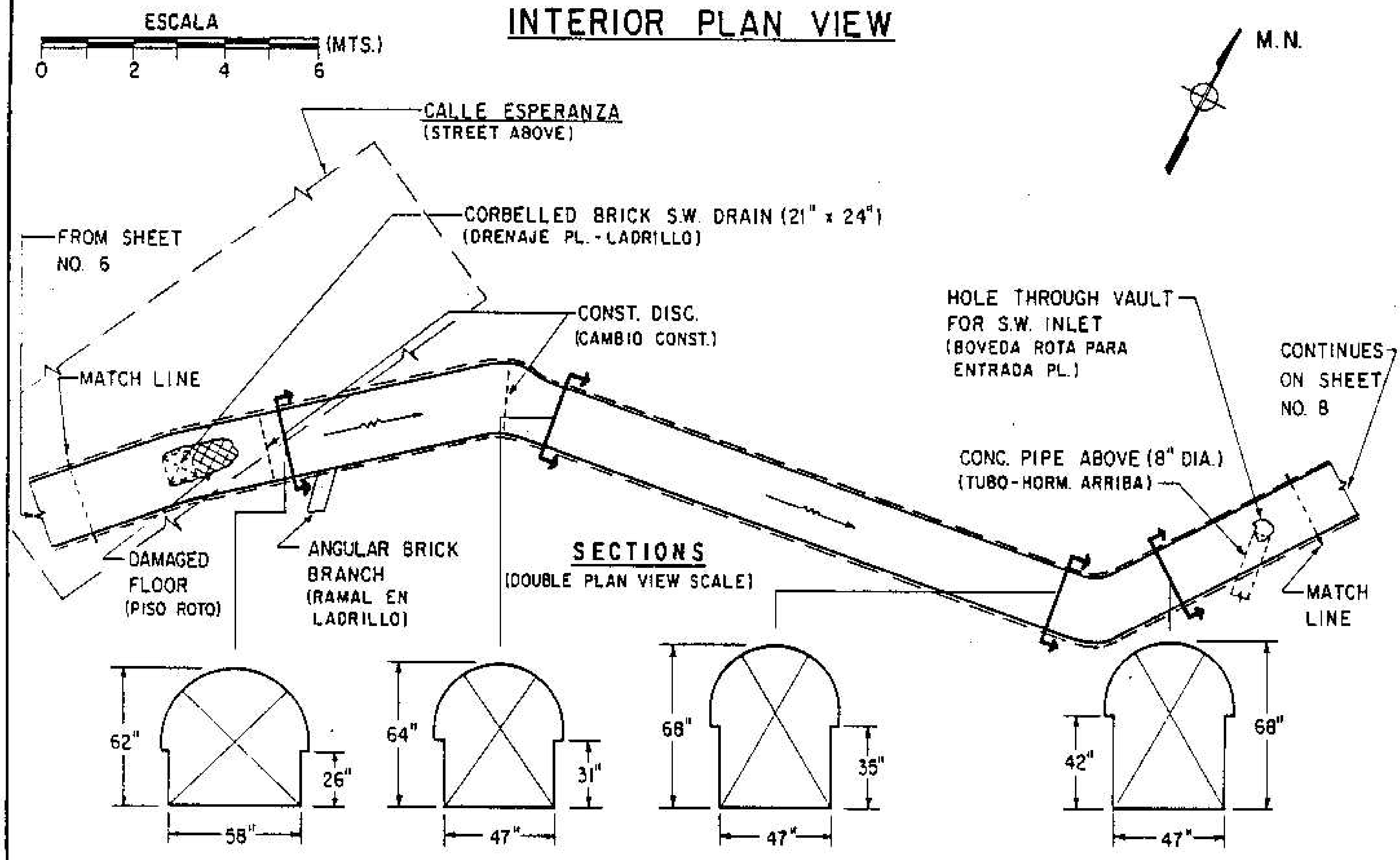
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

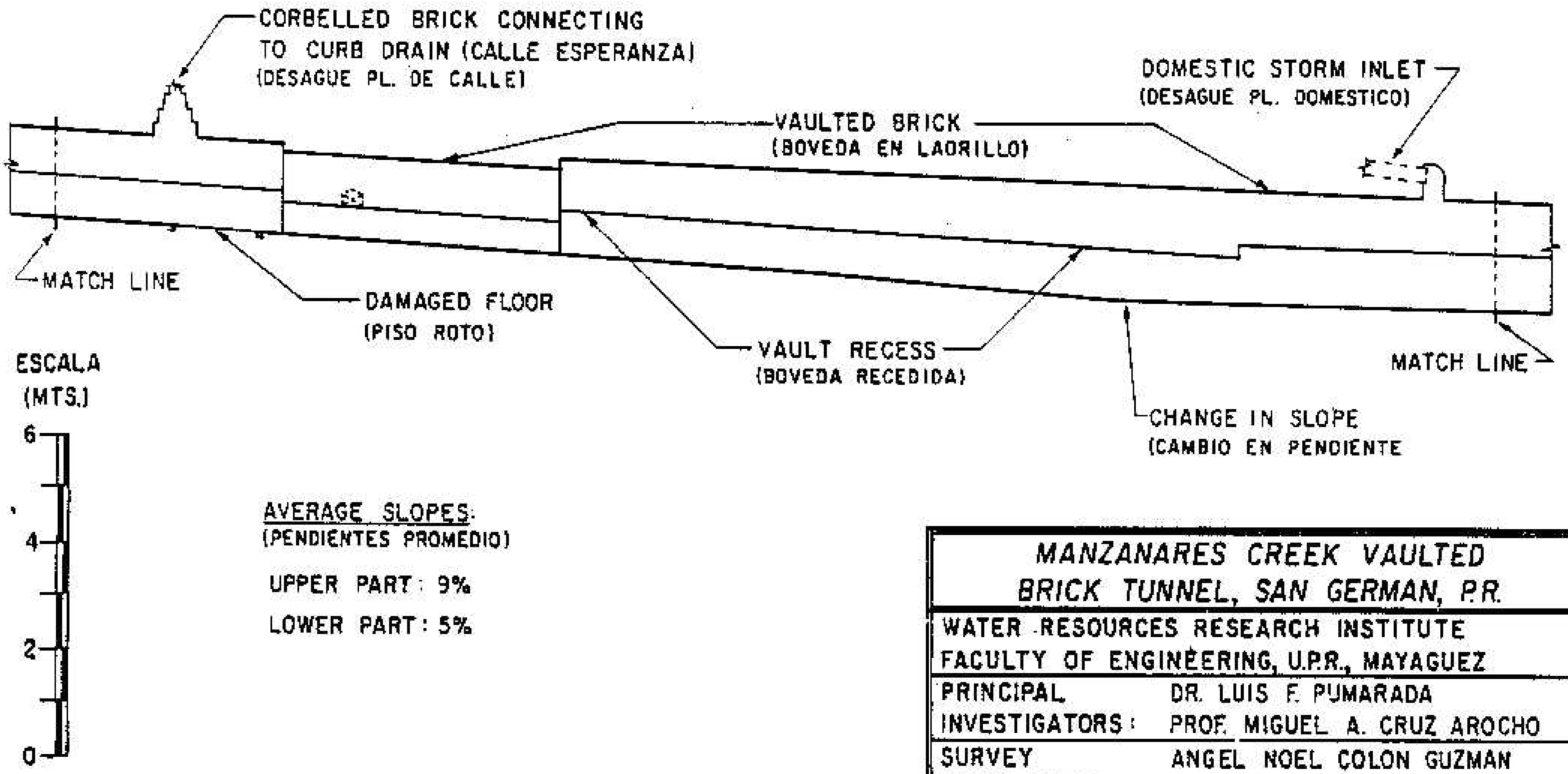
6/30

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



AVERAGE SLOPES:
(PENDIENTES PROMEDIO)

UPPER PART: 9%

LOWER PART: 5%

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

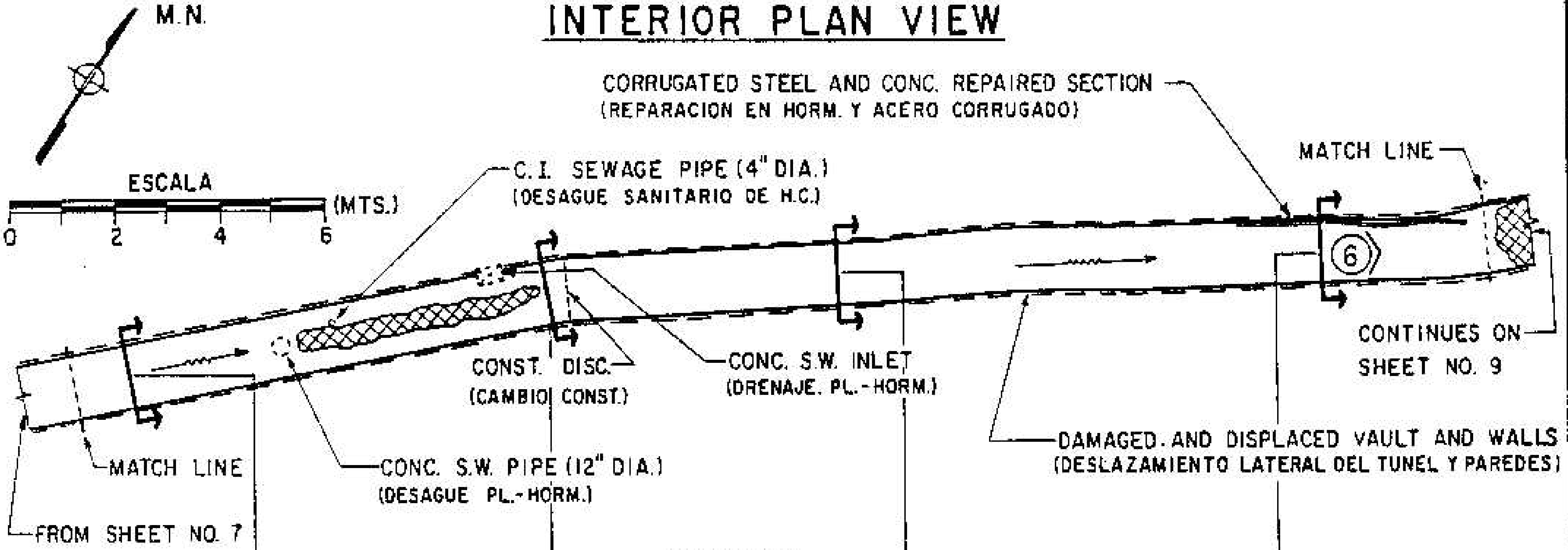
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

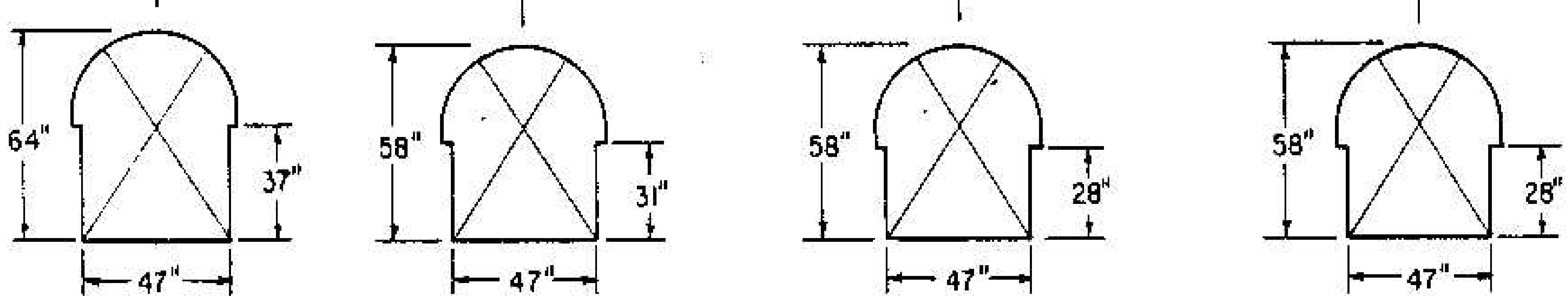
7/30

INTERIOR PLAN VIEW



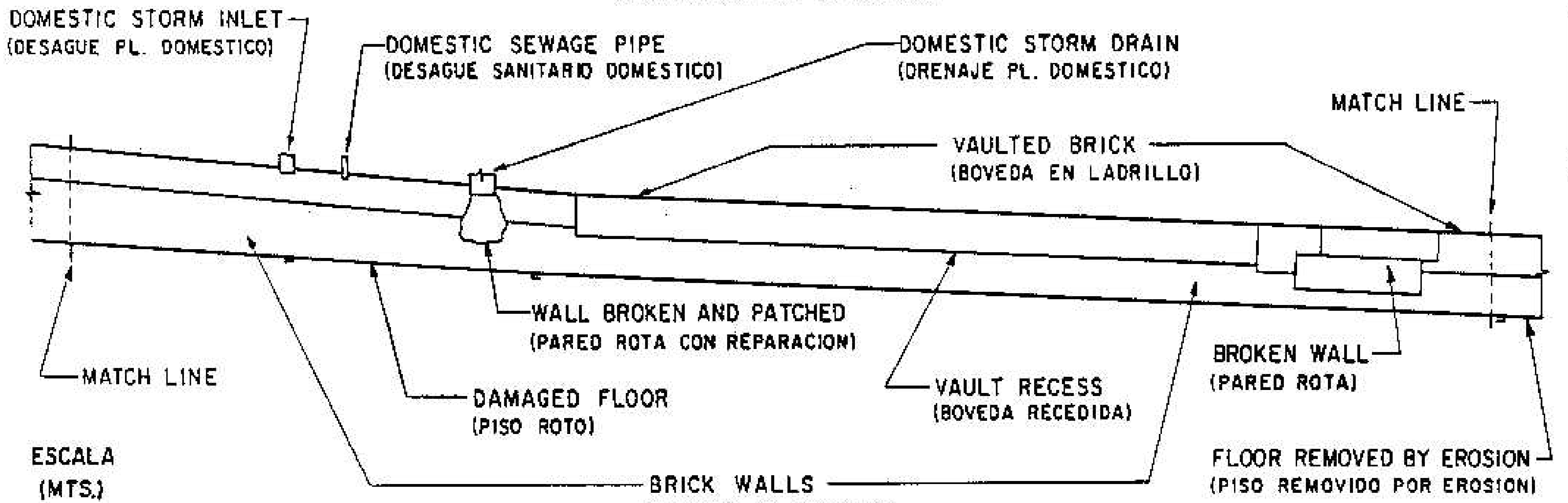
SECTIONS

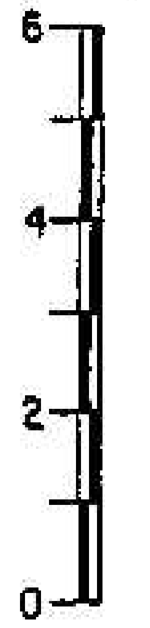
(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

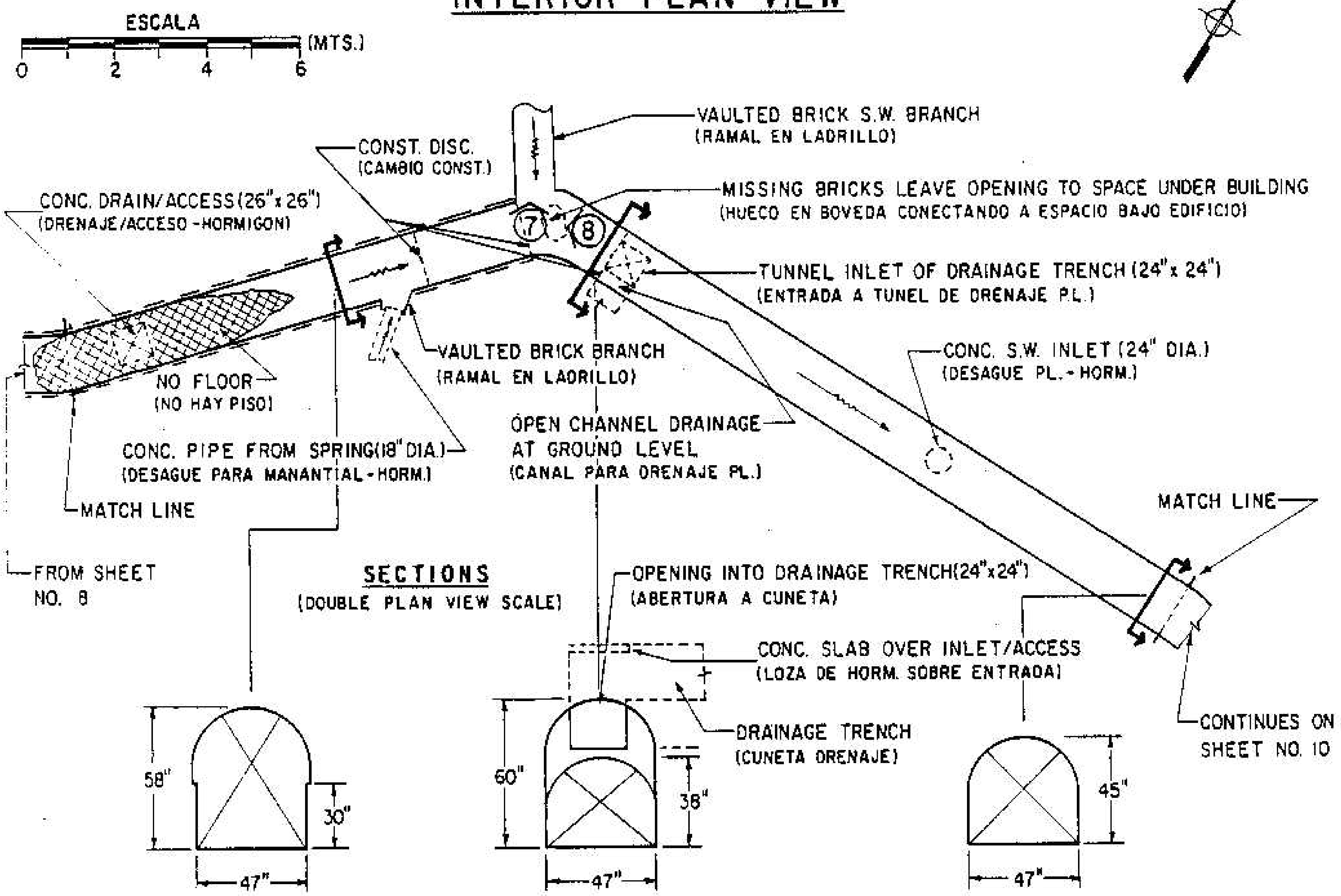
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

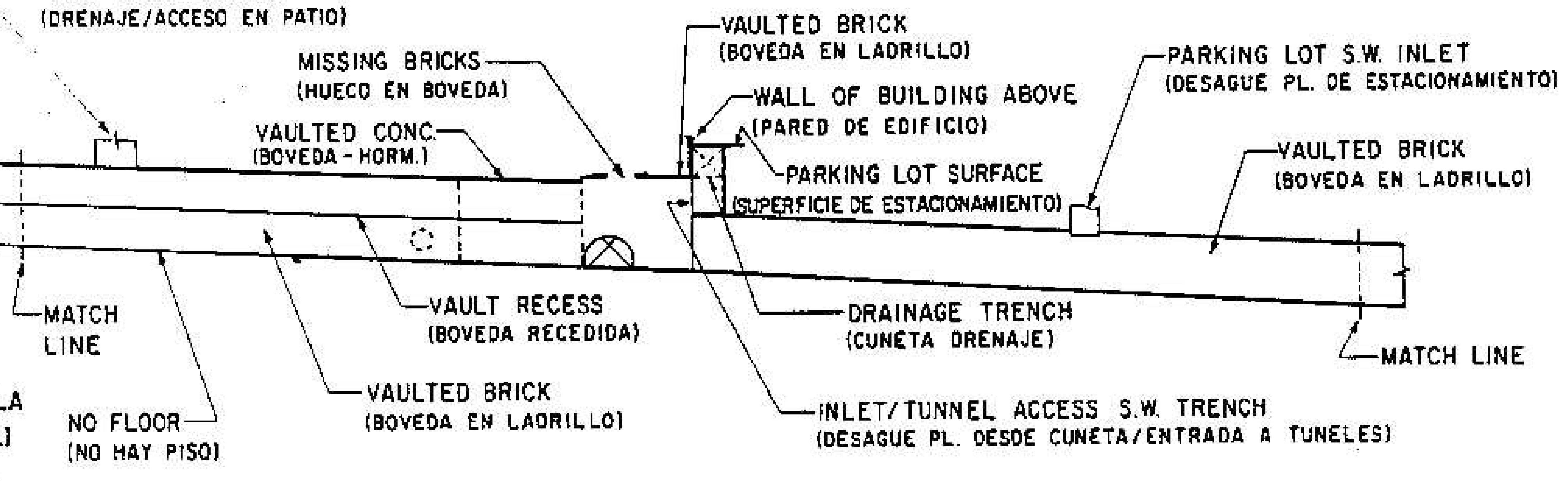
MAY-DECEMBER 1987

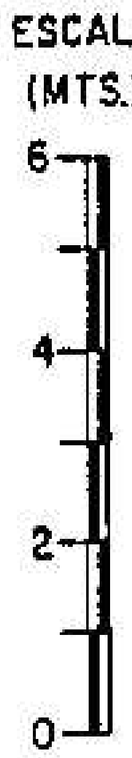
INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





AVERAGE SLOPE: ≈ -3%
(PENDIENTE PROMEDIO)

⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

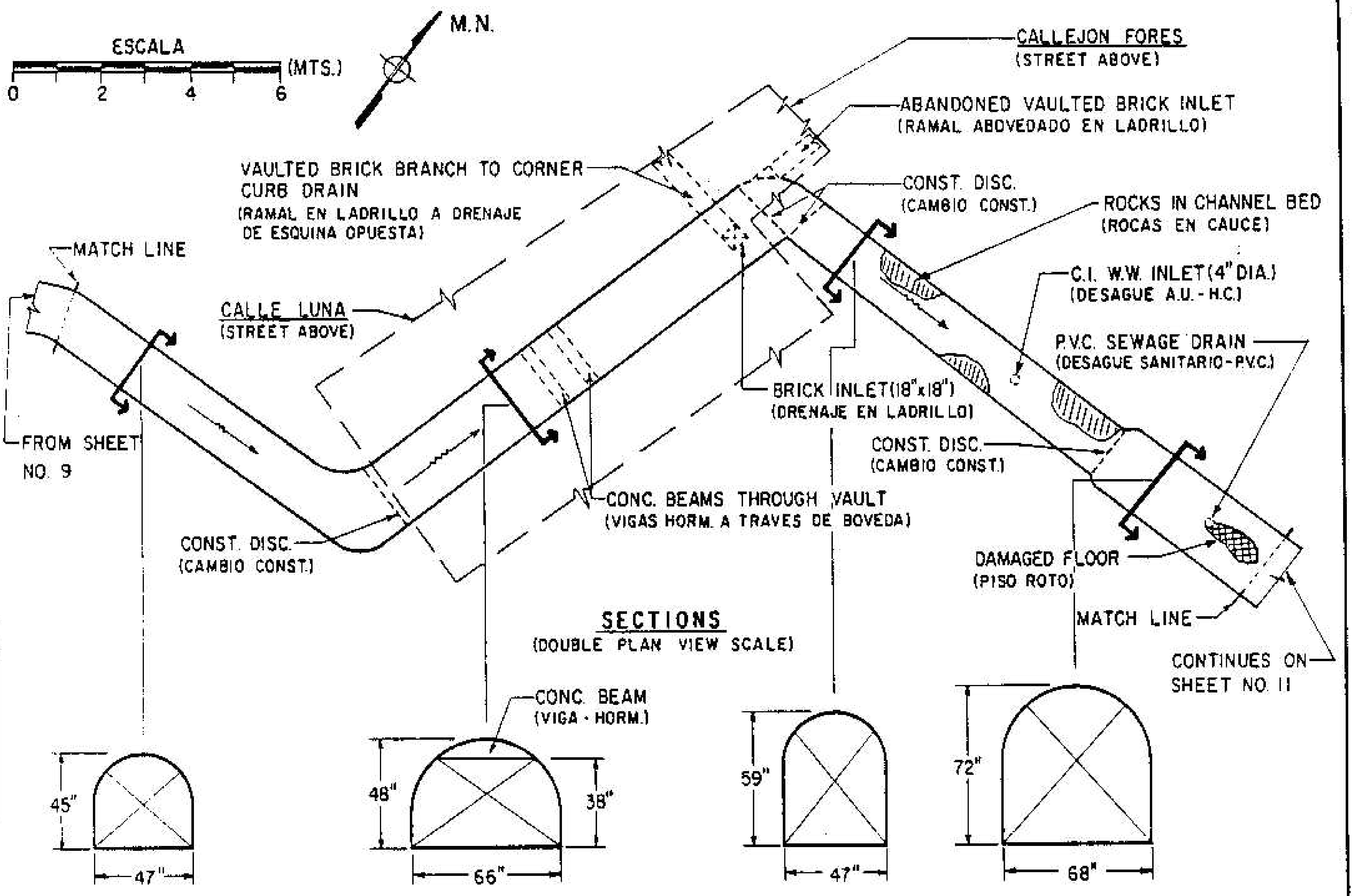
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

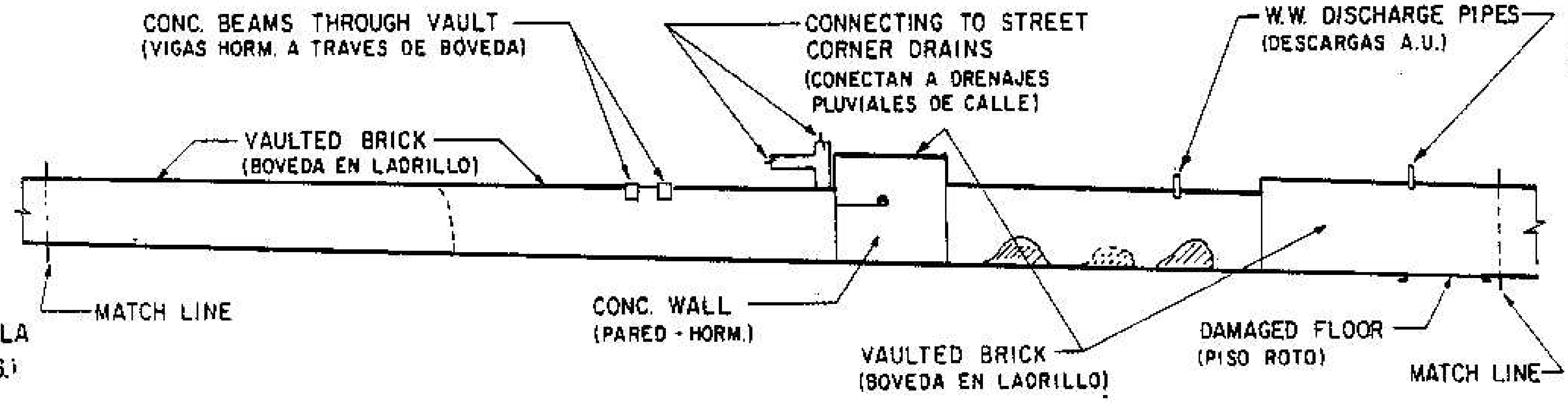
MAY-DECEMBER 1987

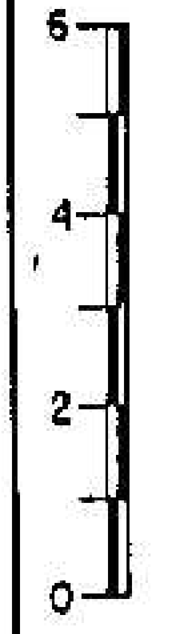
INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





AVERAGE SLOPE: ≈ -3%
(PENDIENTE PROMEDIO)

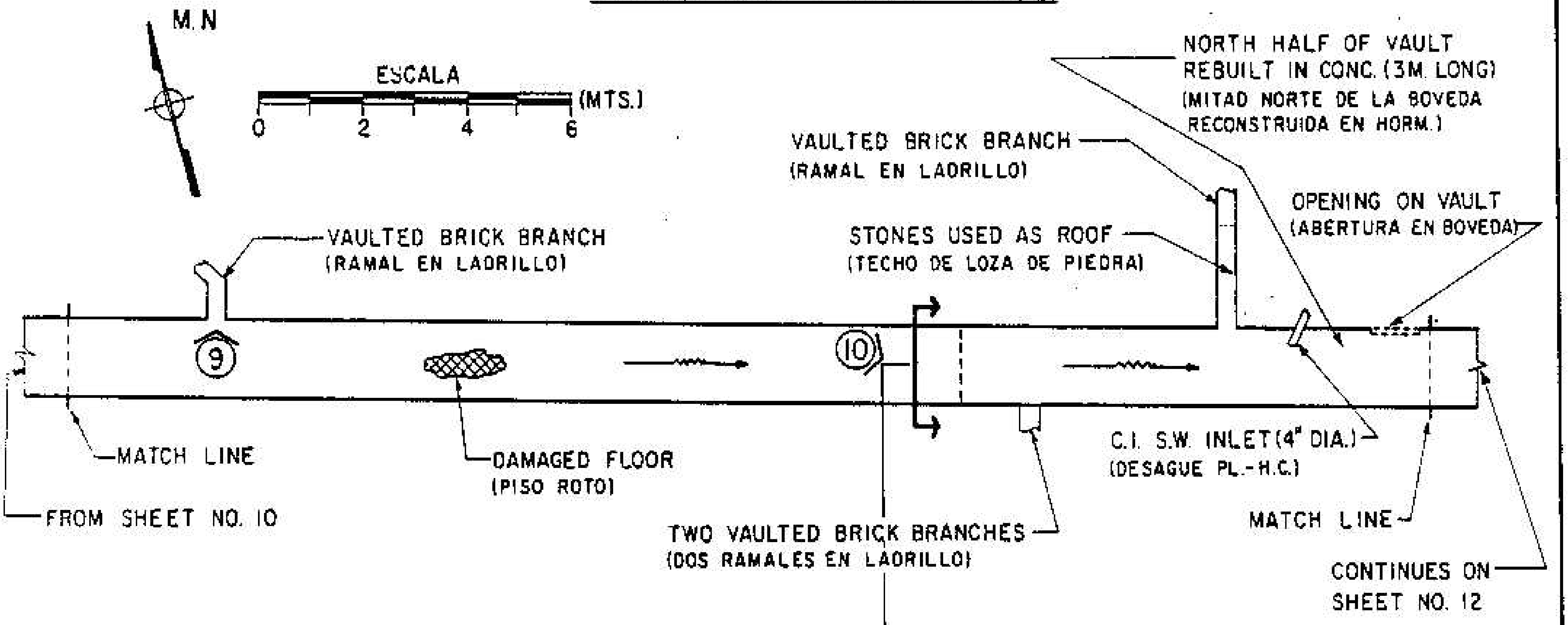
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

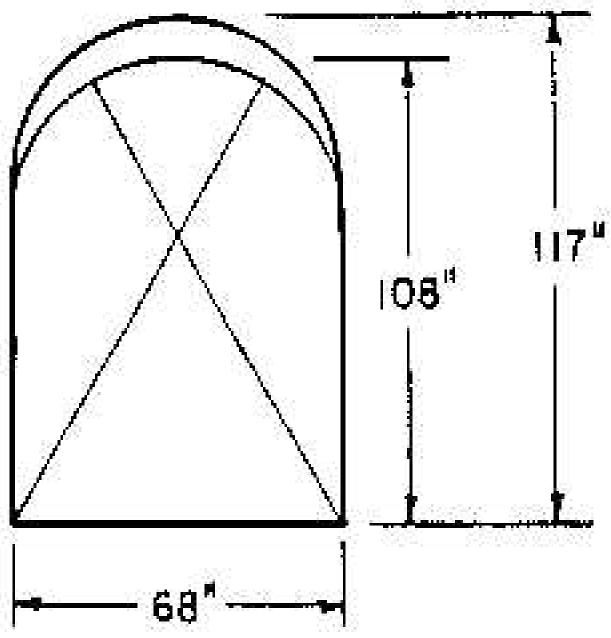
MAY-DECEMBER 1987

INTERIOR PLAN VIEW



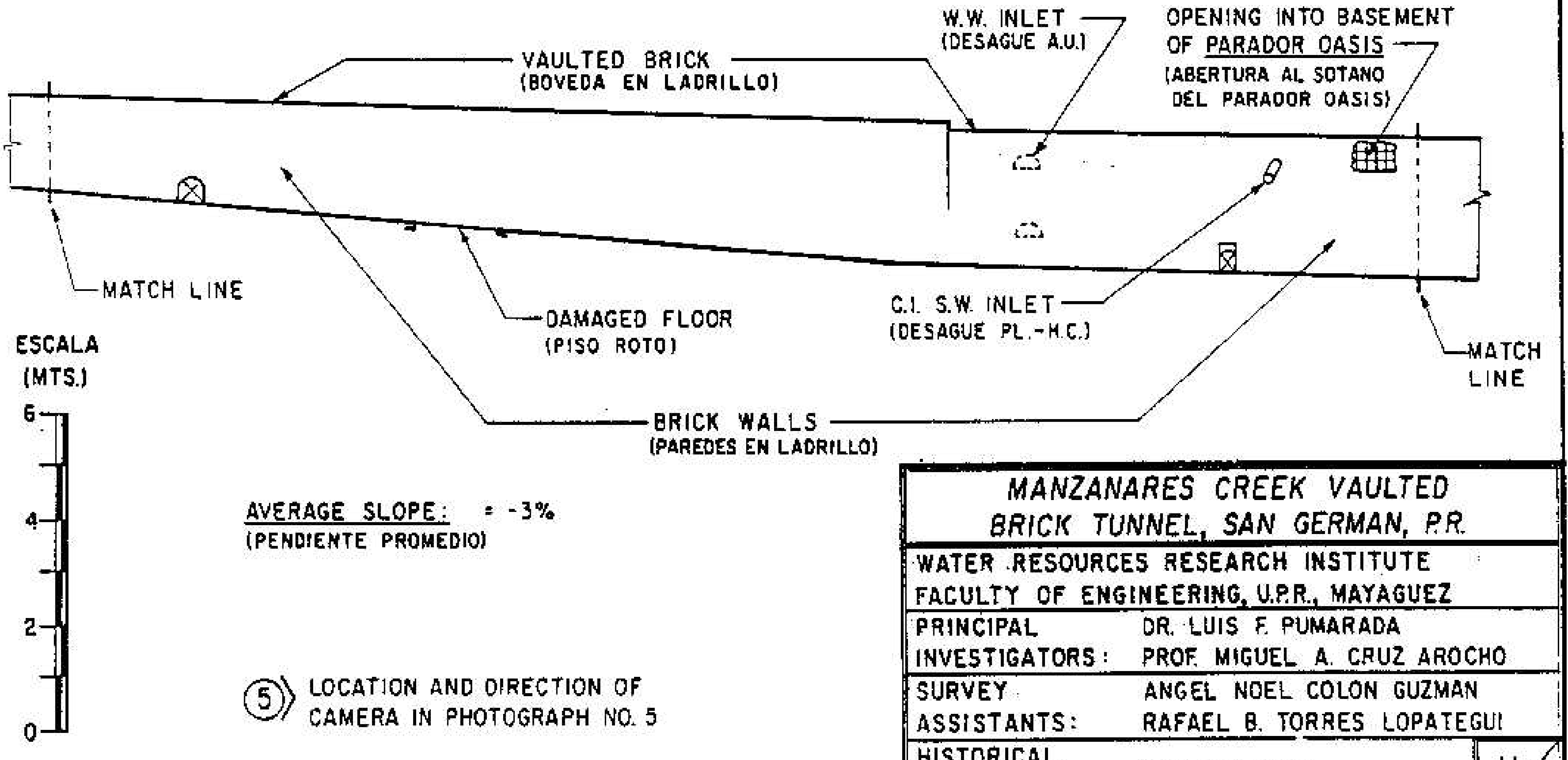
SECTION

(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



AVERAGE SLOPE: = -3%
(PENDIENTE PROMEDIO)

⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

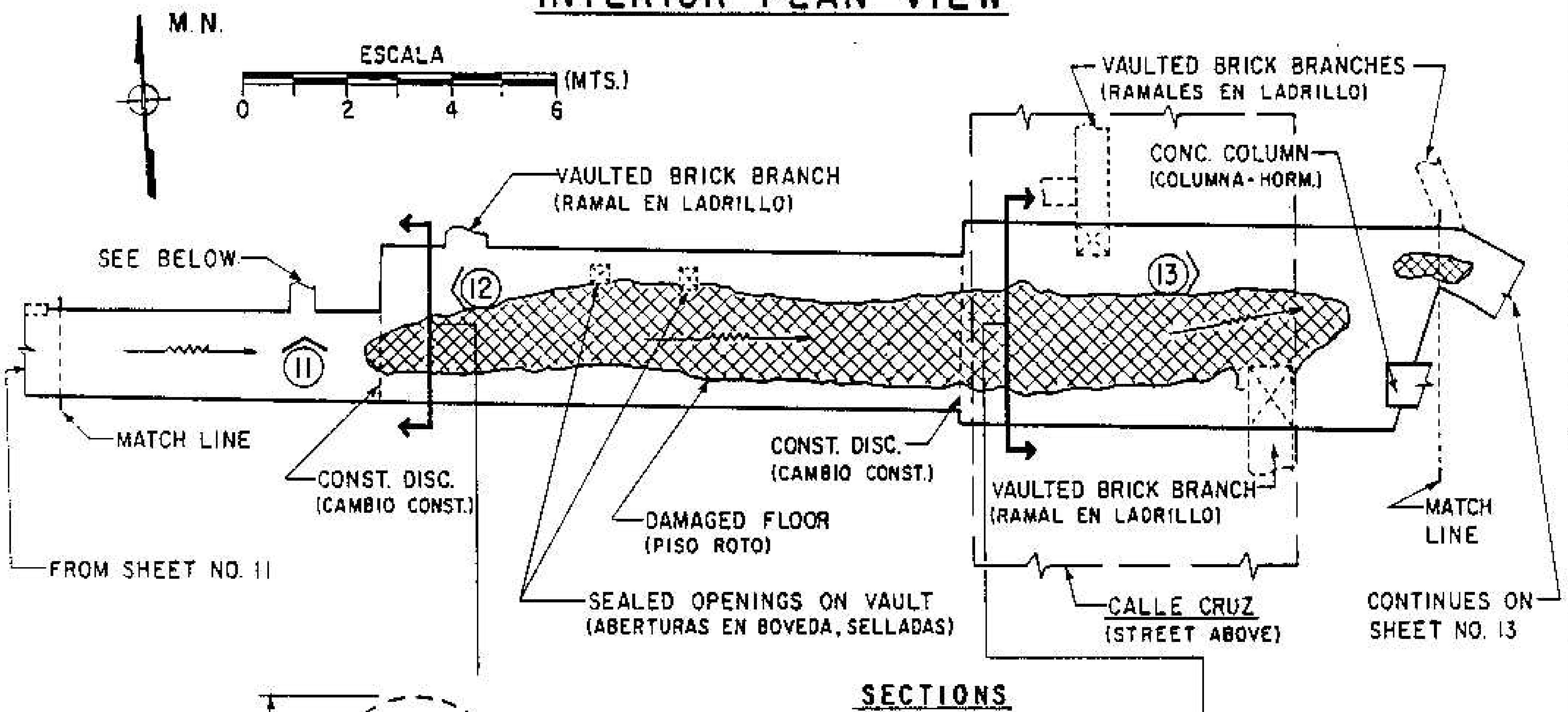
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

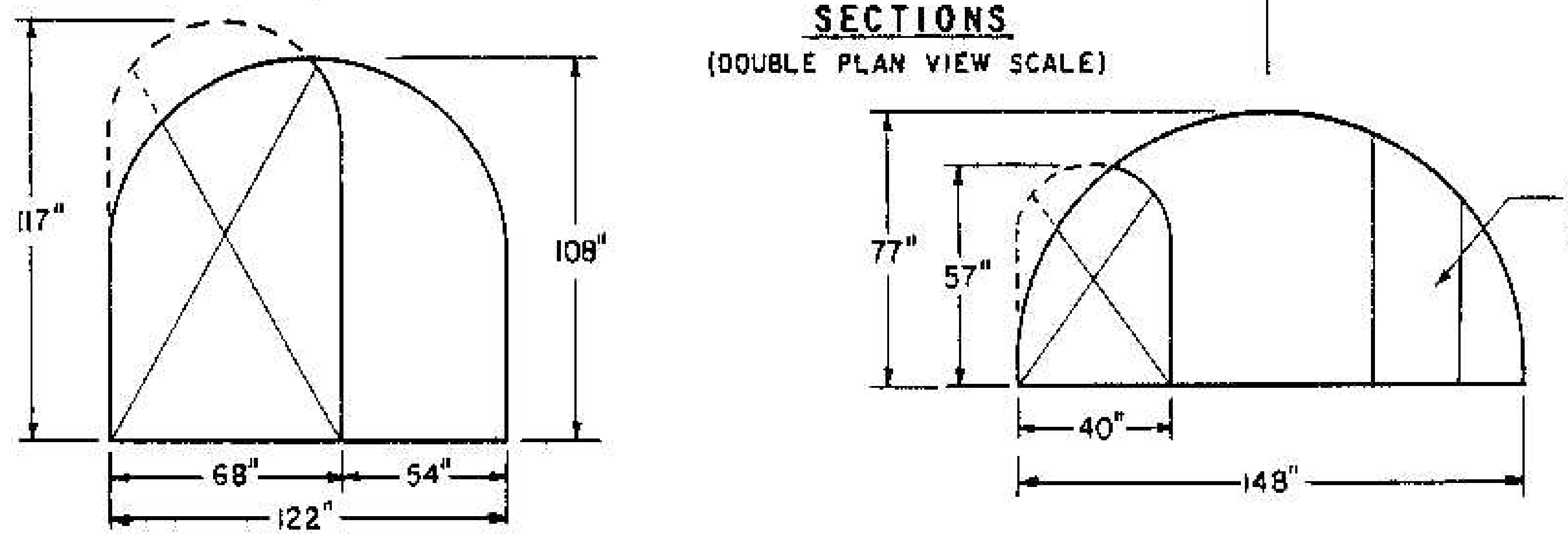
MAY-DECEMBER 1987

INTERIOR PLAN VIEW



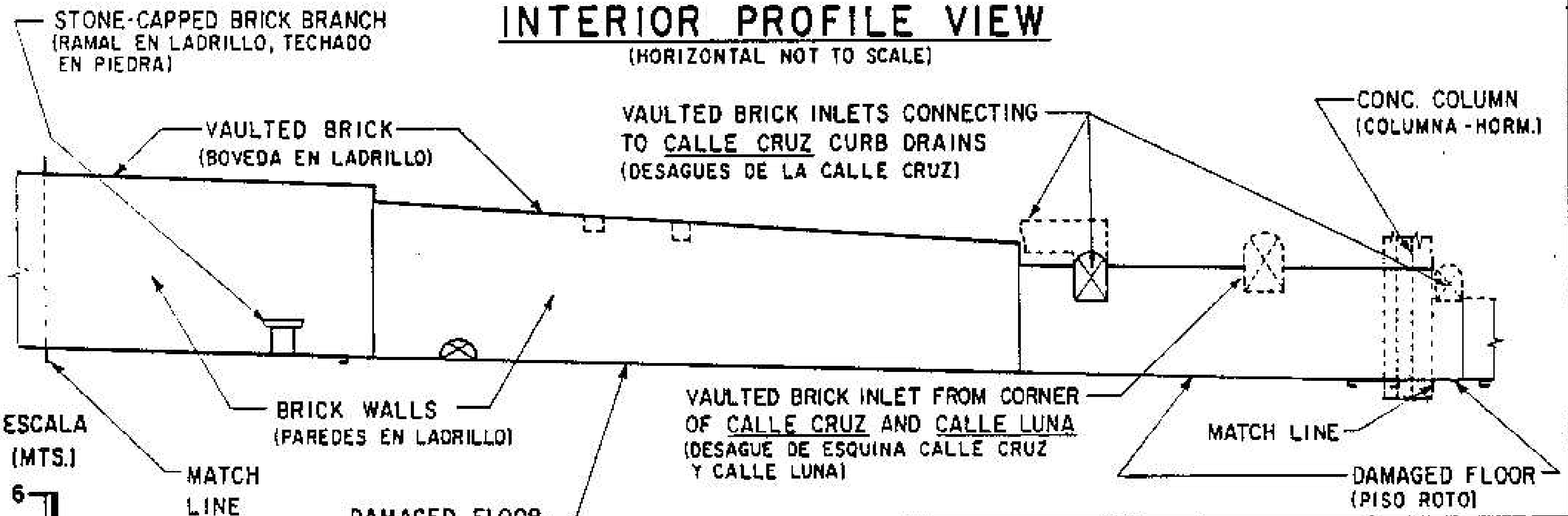
SECTIONS

(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



AVERAGE SLOPE: = -3%
(PENDIENTE PROMEDIO)

⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

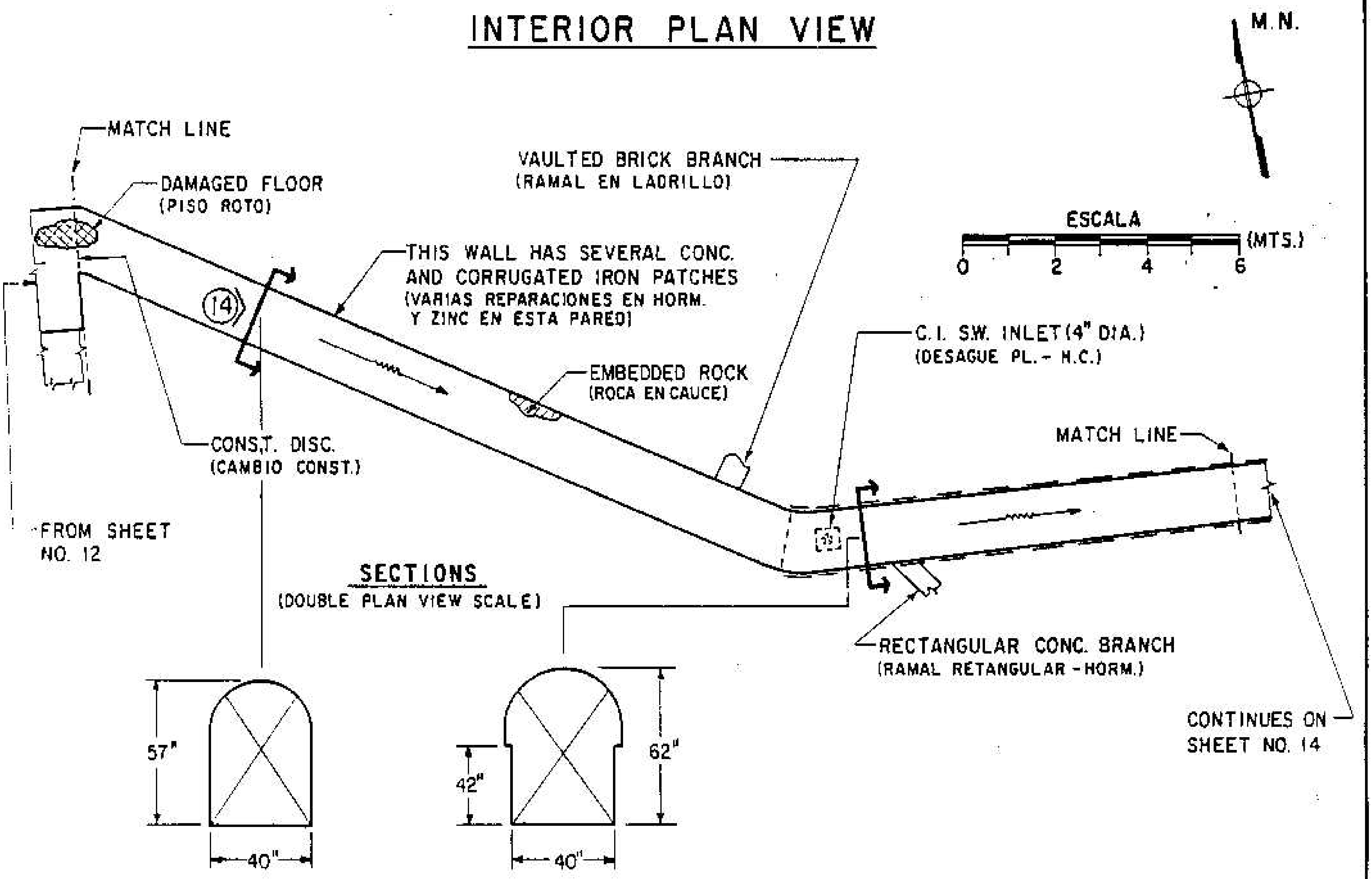
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

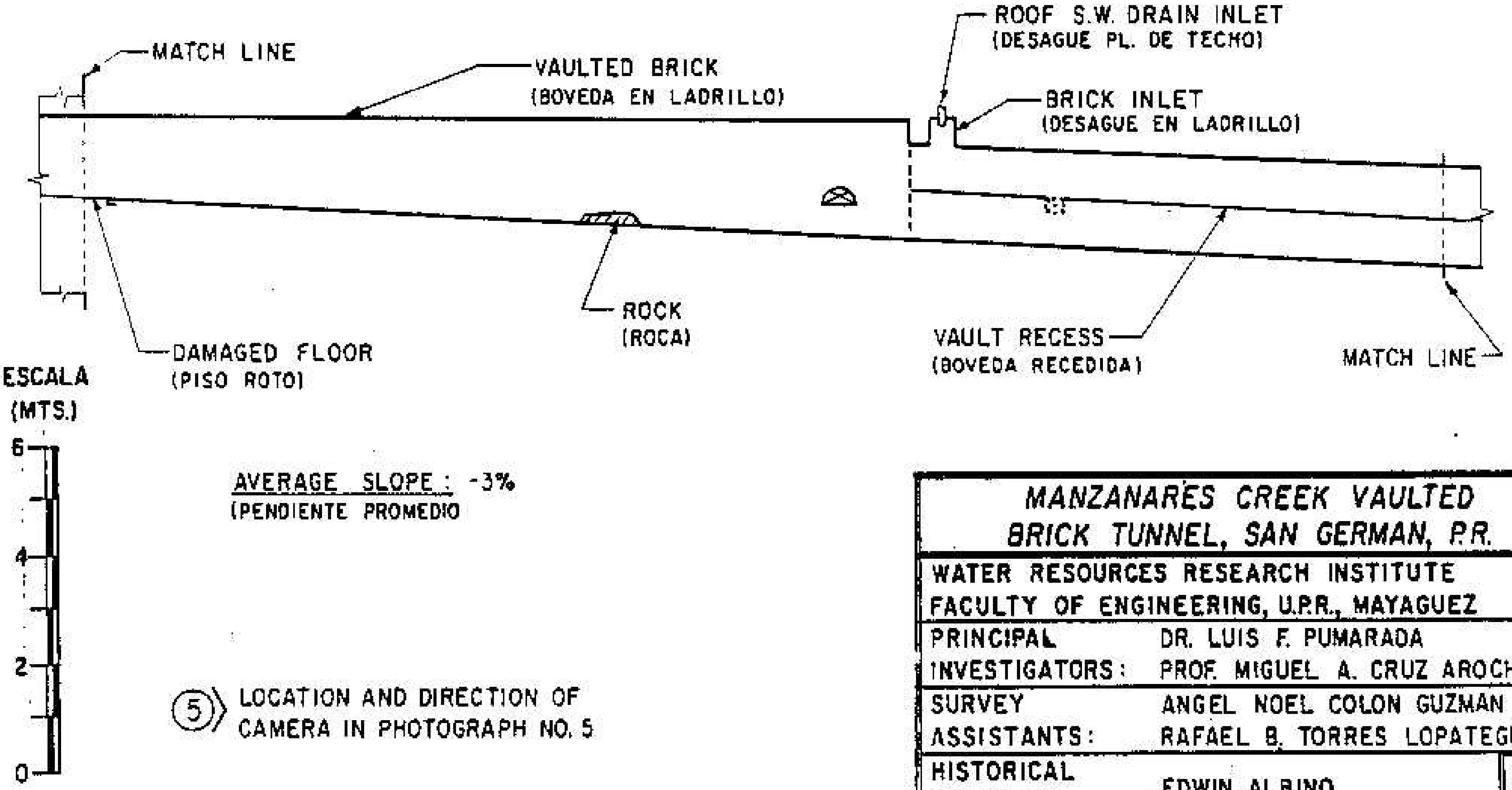
12/30

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



AVERAGE SLOPE: -3%
(PENDIENTE PROMEDIO)

⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

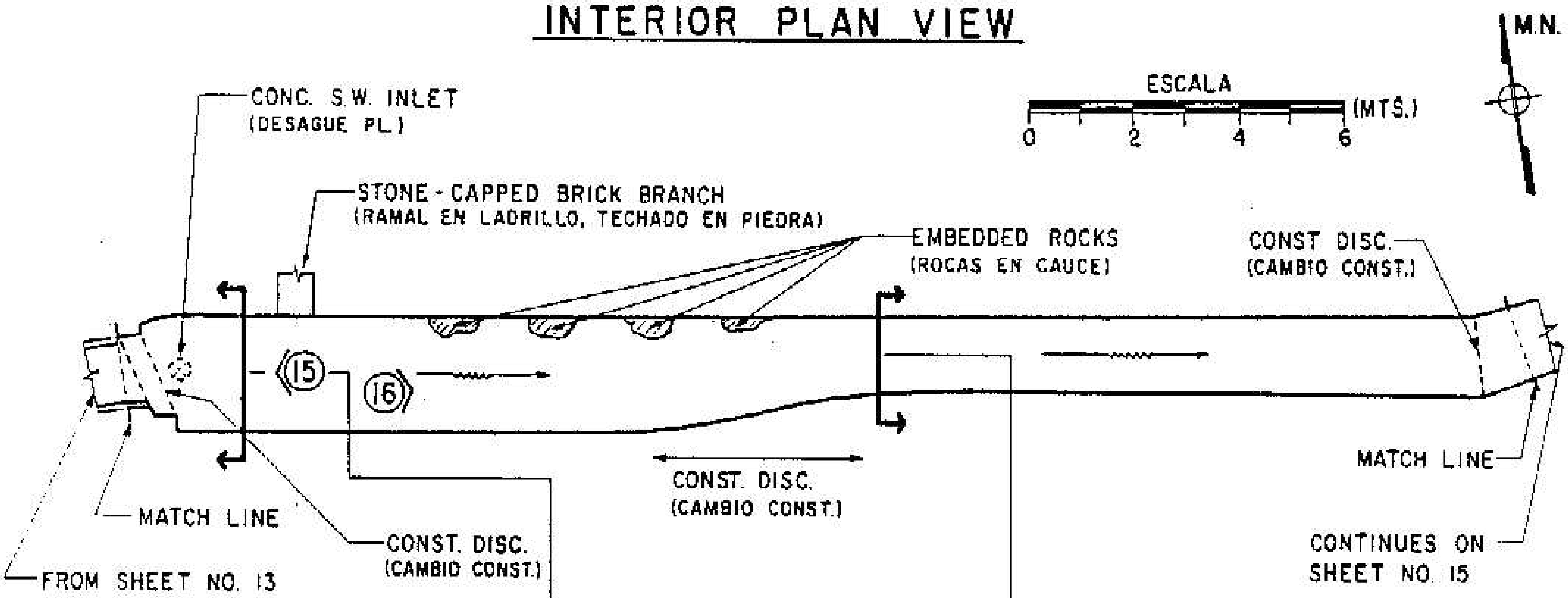
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

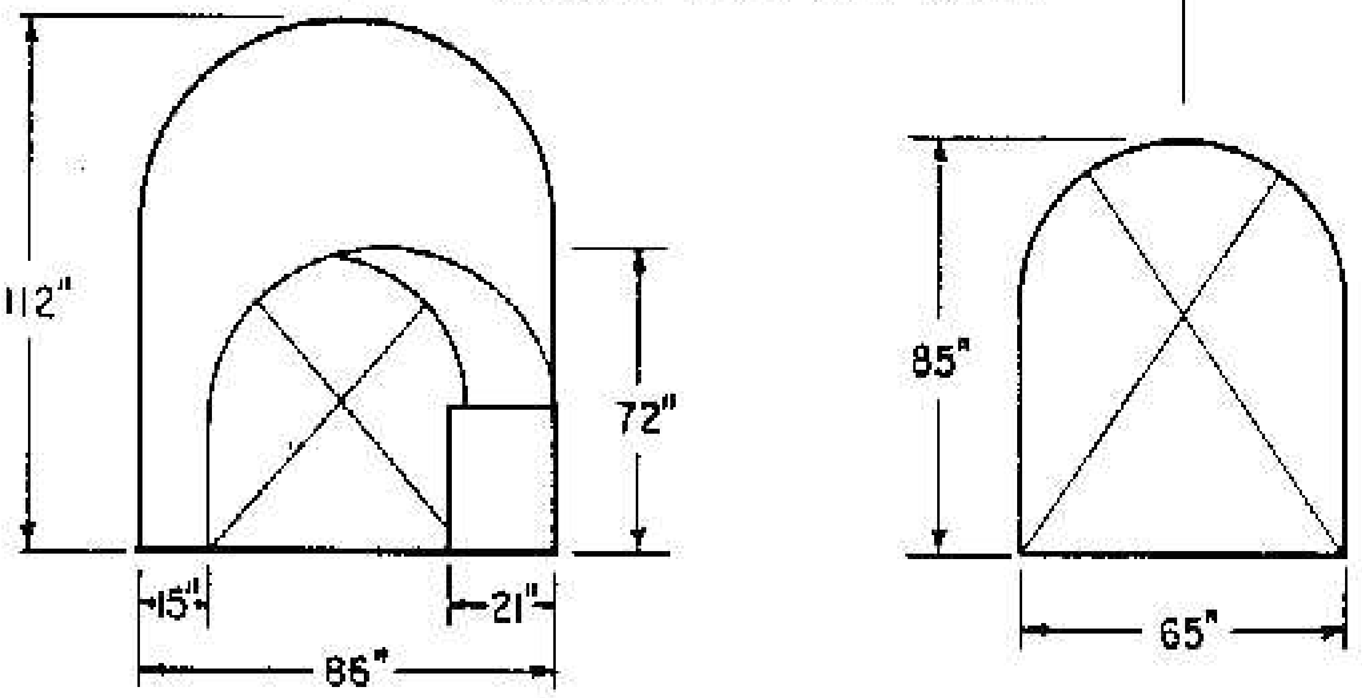
13/30

INTERIOR PLAN VIEW



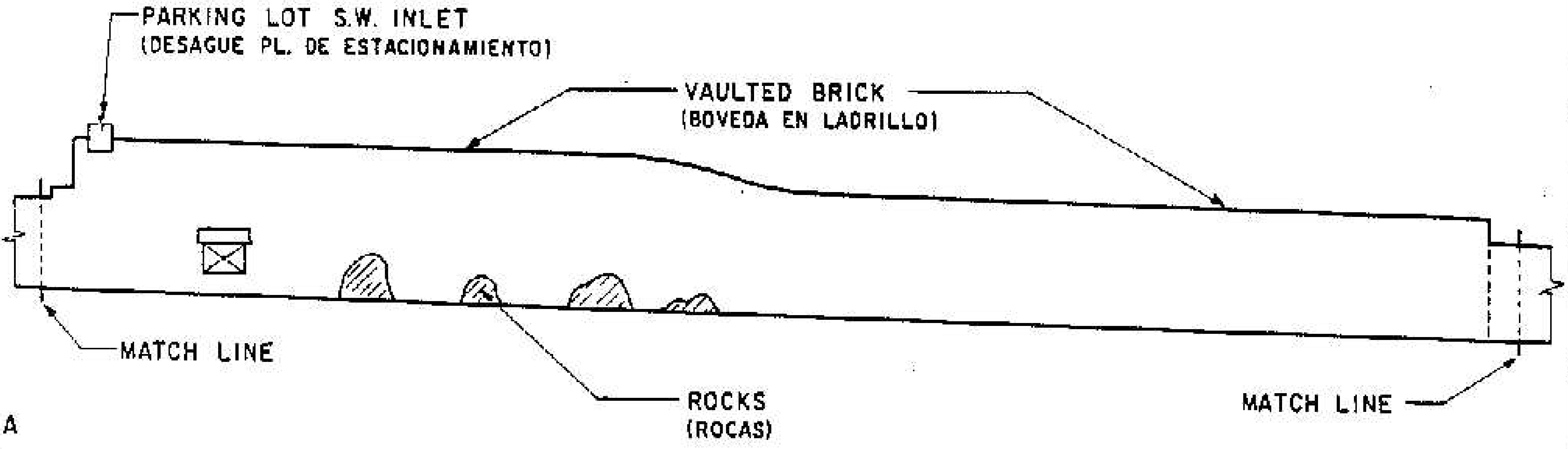
SECTIONS

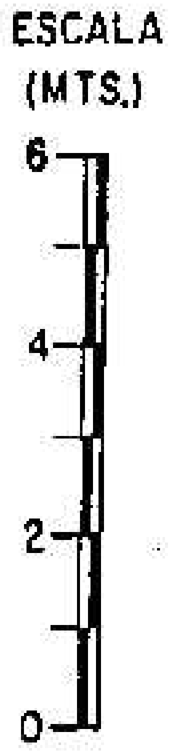
(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





AVERAGE SLOPE: ≈ -3%
(PENDIENTE PROMEDIO)

⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

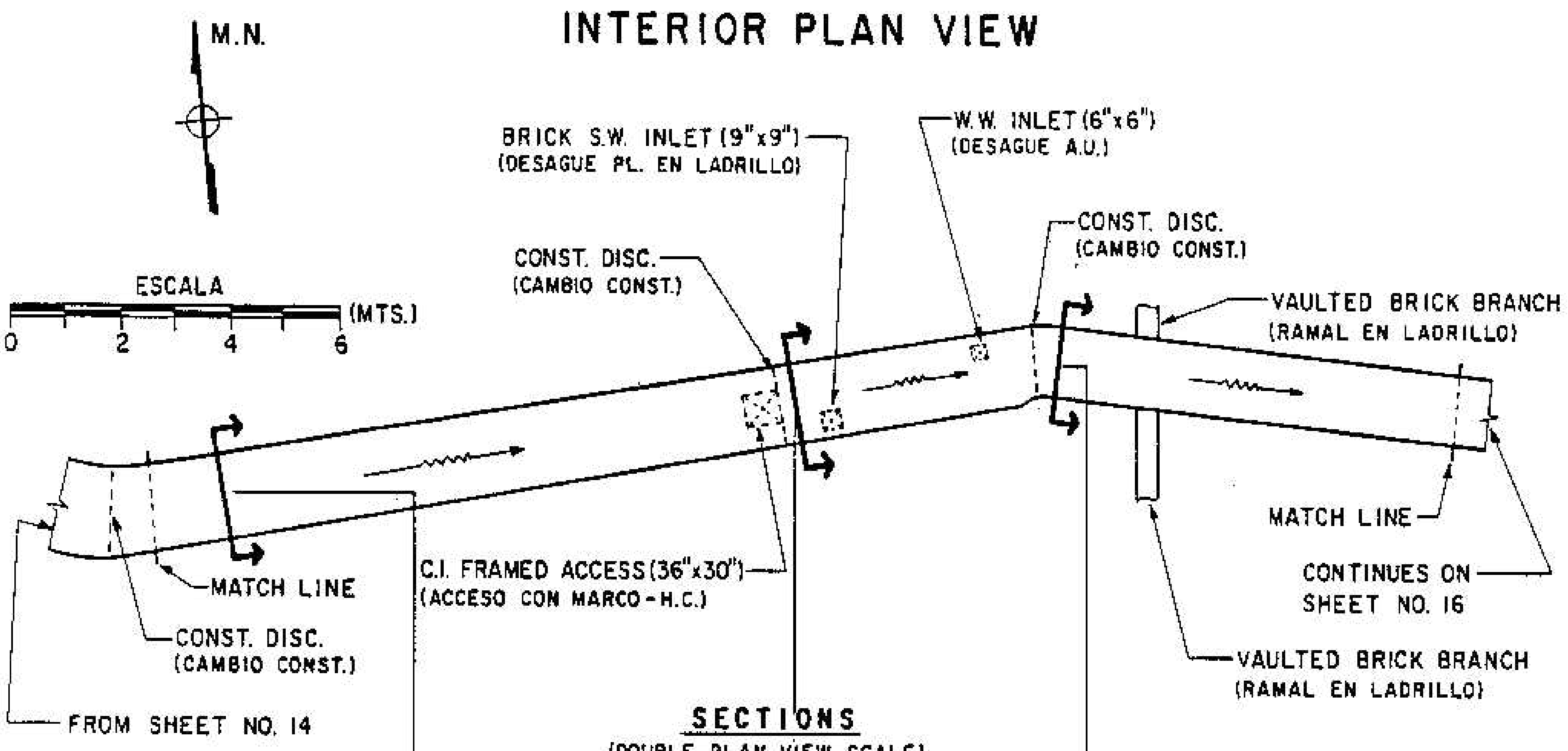
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

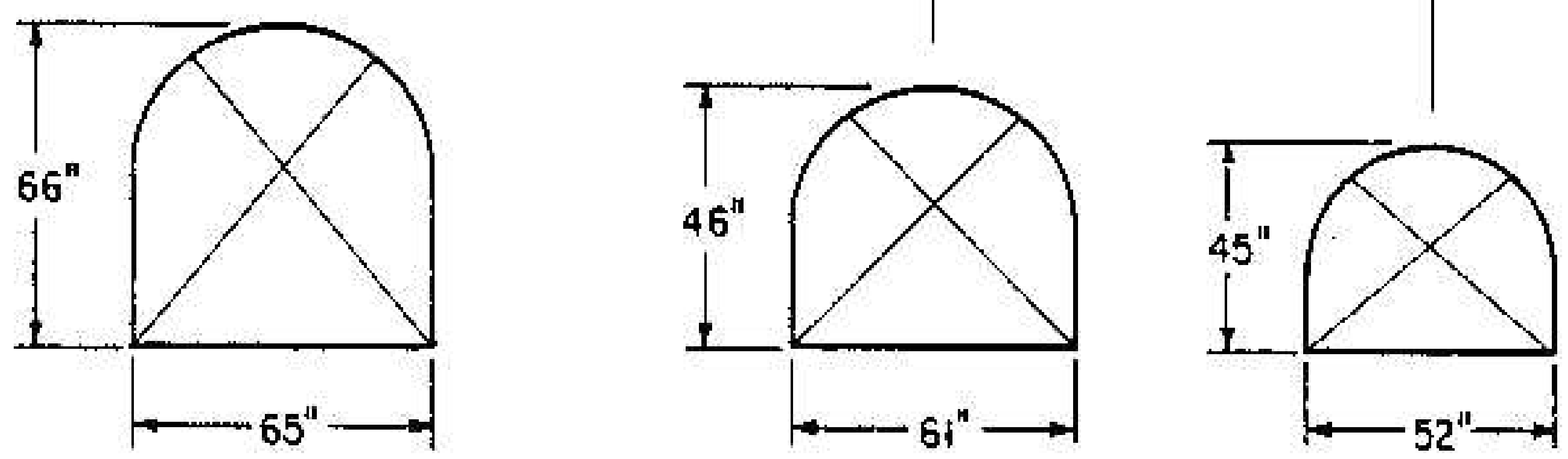
MAY-DECEMBER 1987

INTERIOR PLAN VIEW



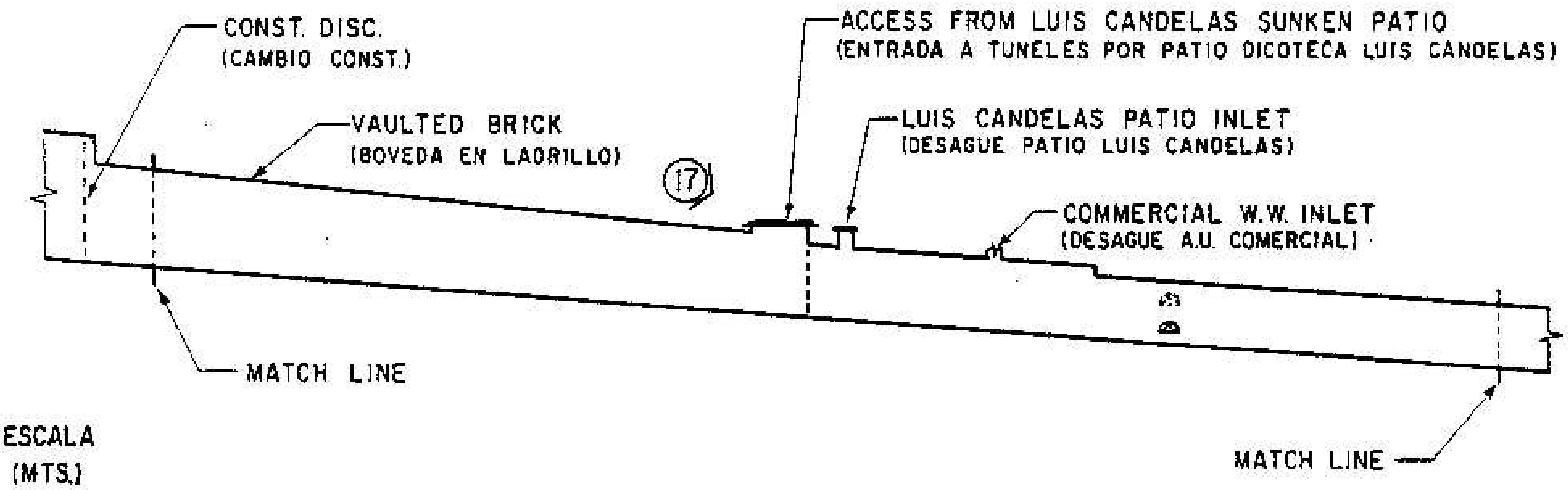
SECTIONS

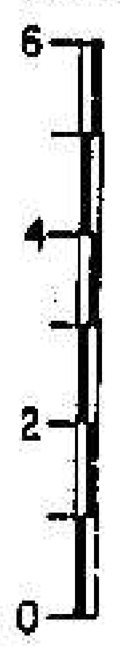
(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

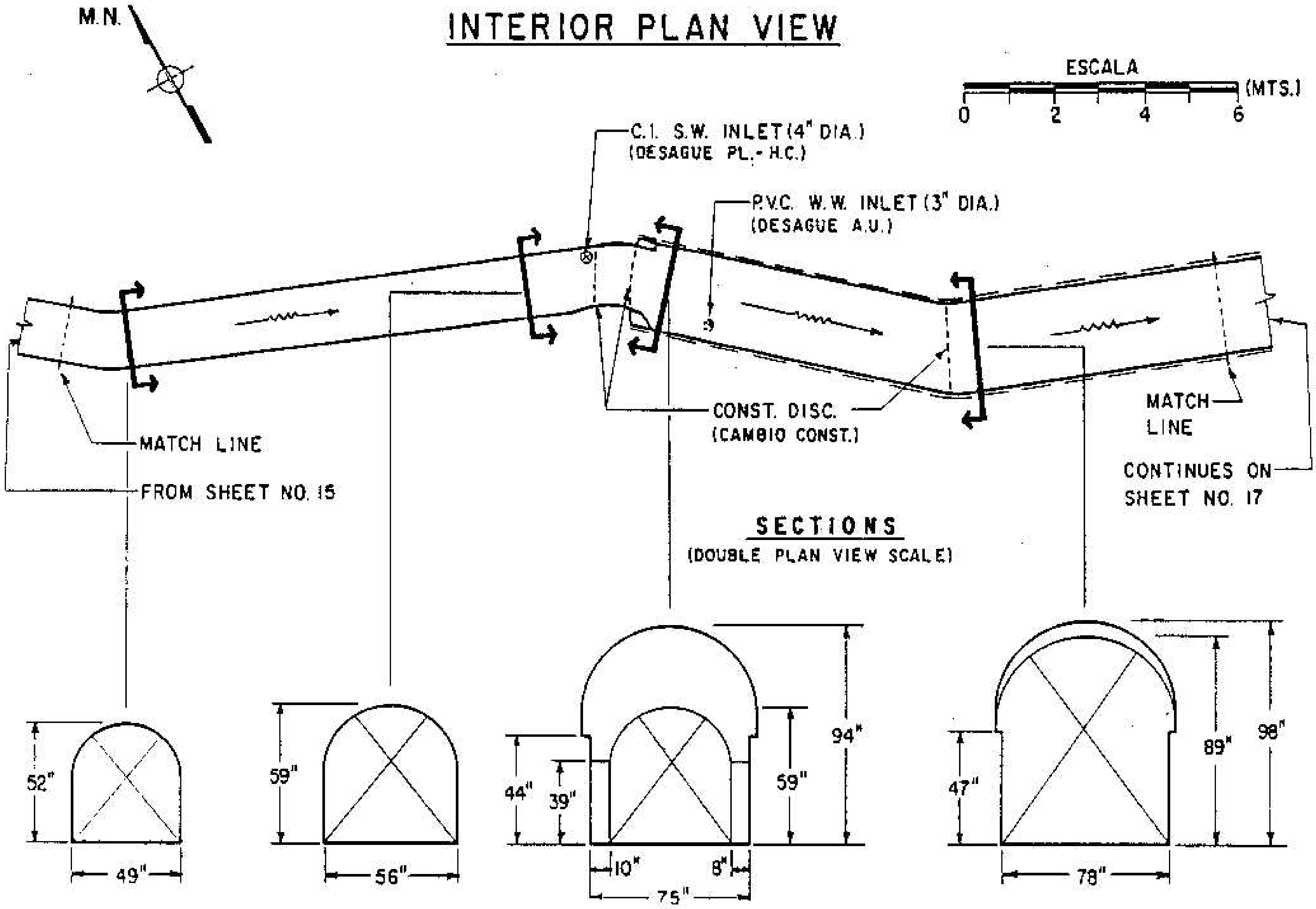
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

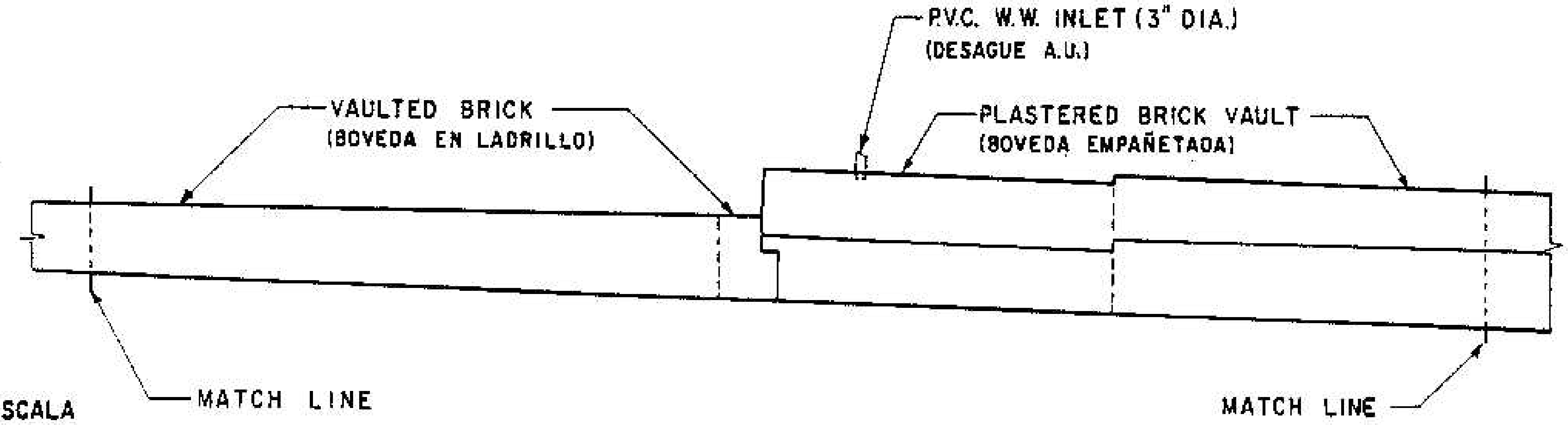
15/30

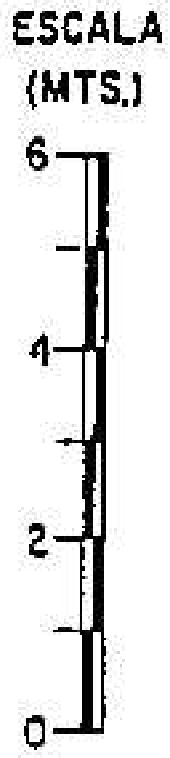
INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

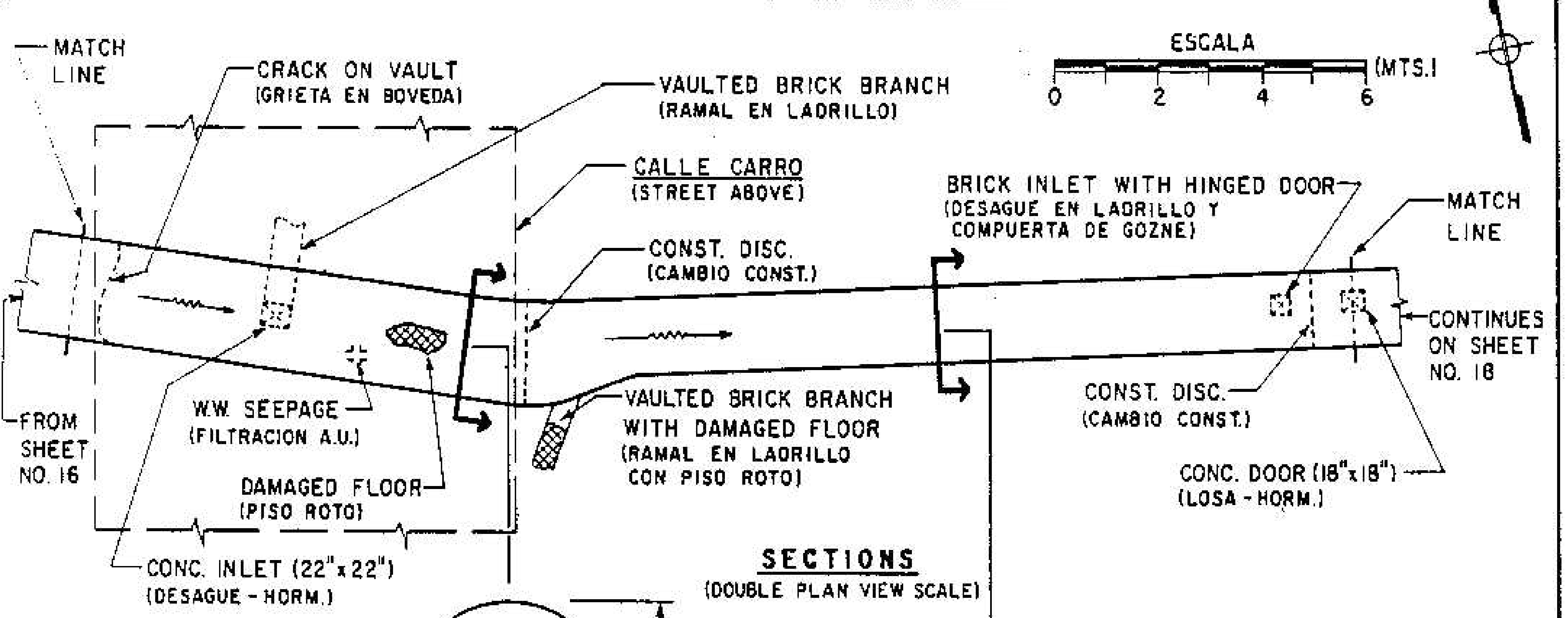
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

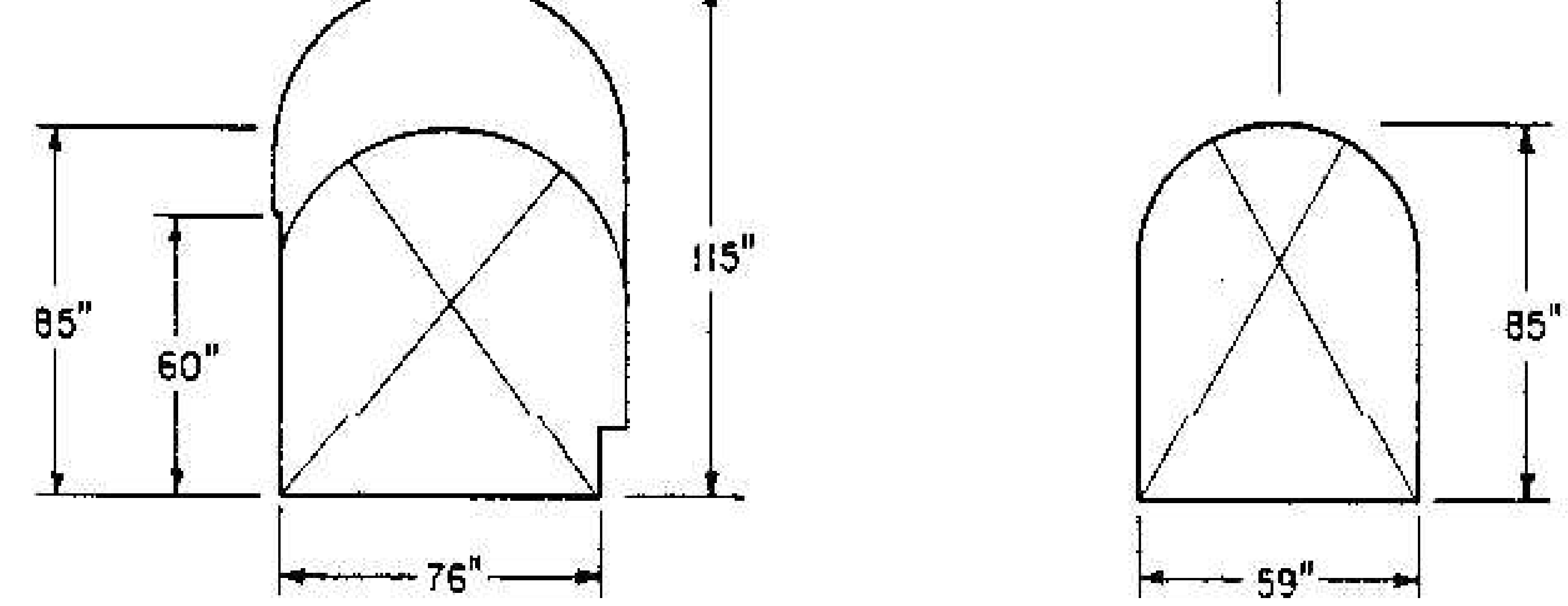
16/30

INTERIOR PLAN VIEW



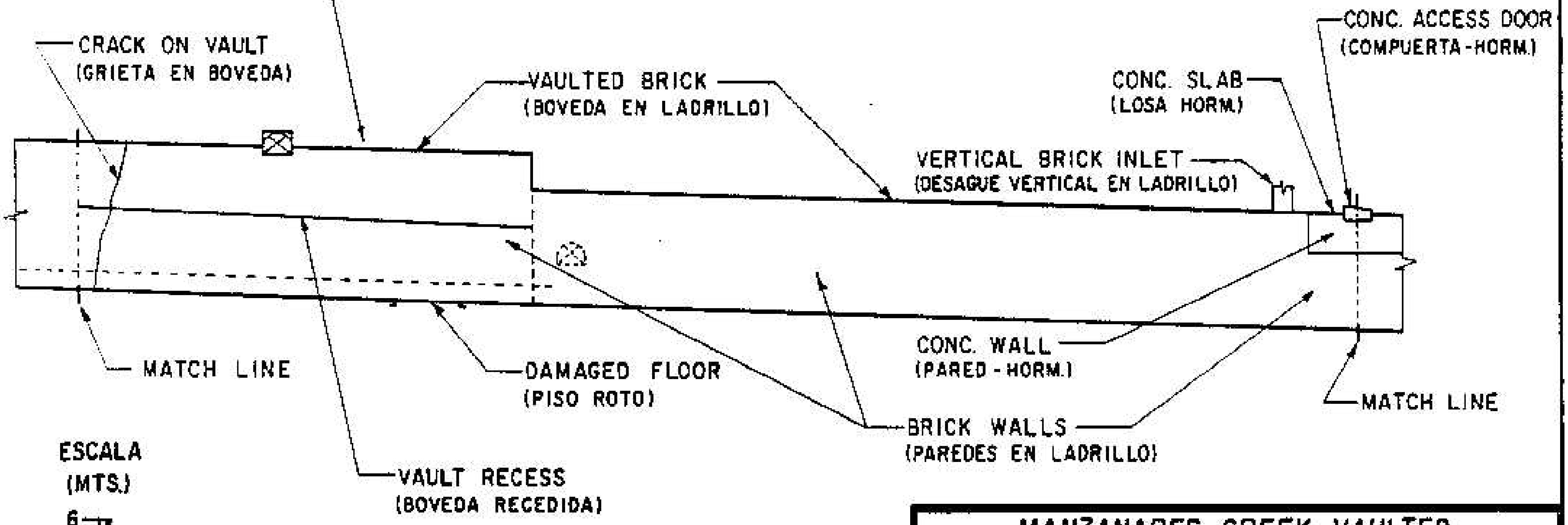
SECTIONS

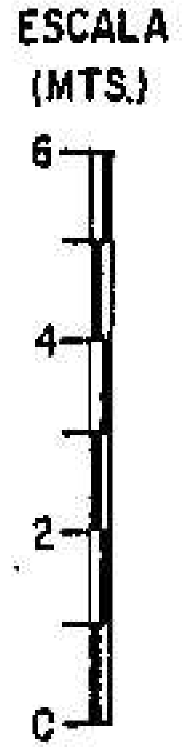
(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





MANZANARES CREEK VAULTED BRICK TUNNEL,-SAN GERMAN, P.R.

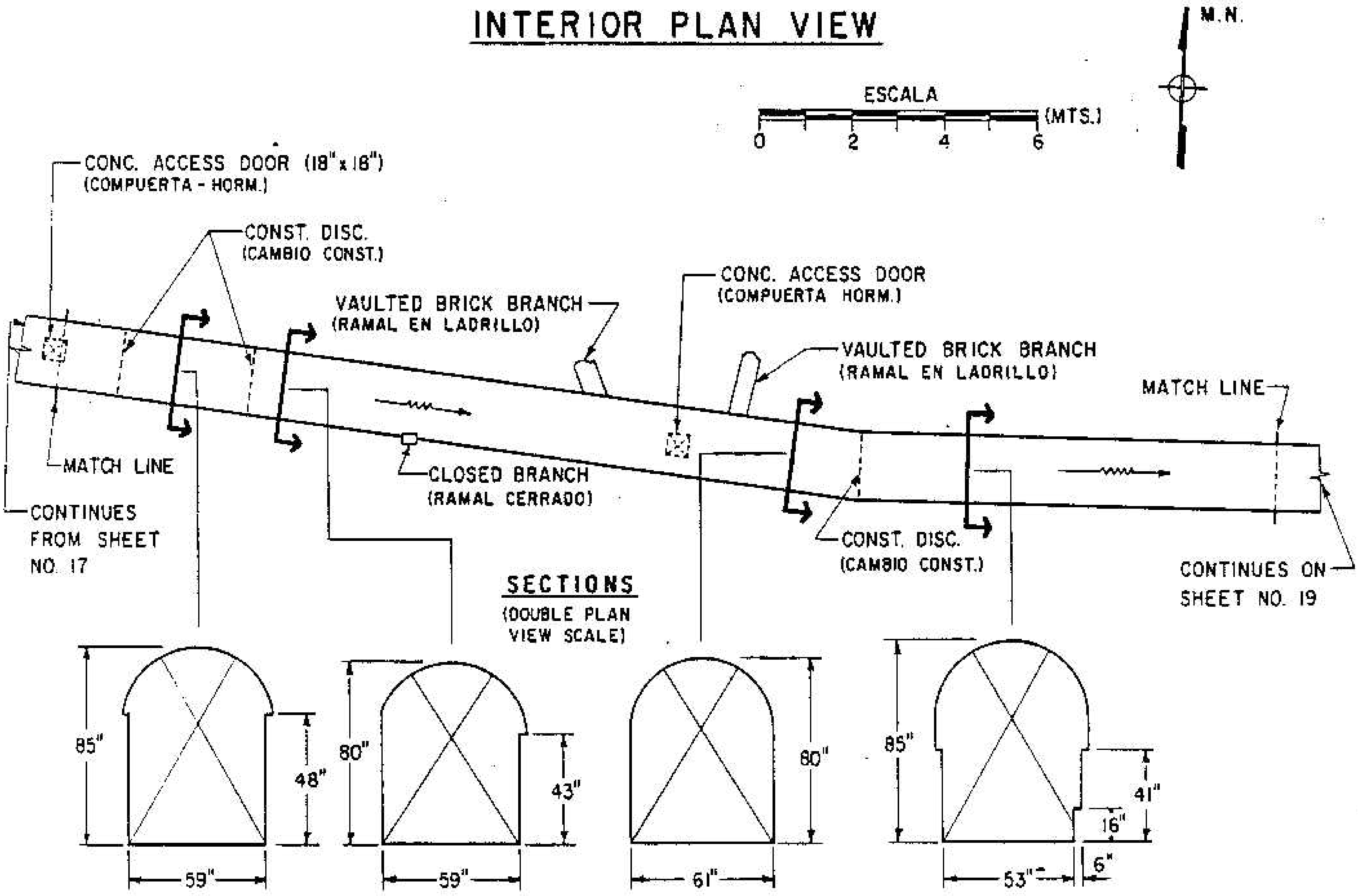
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

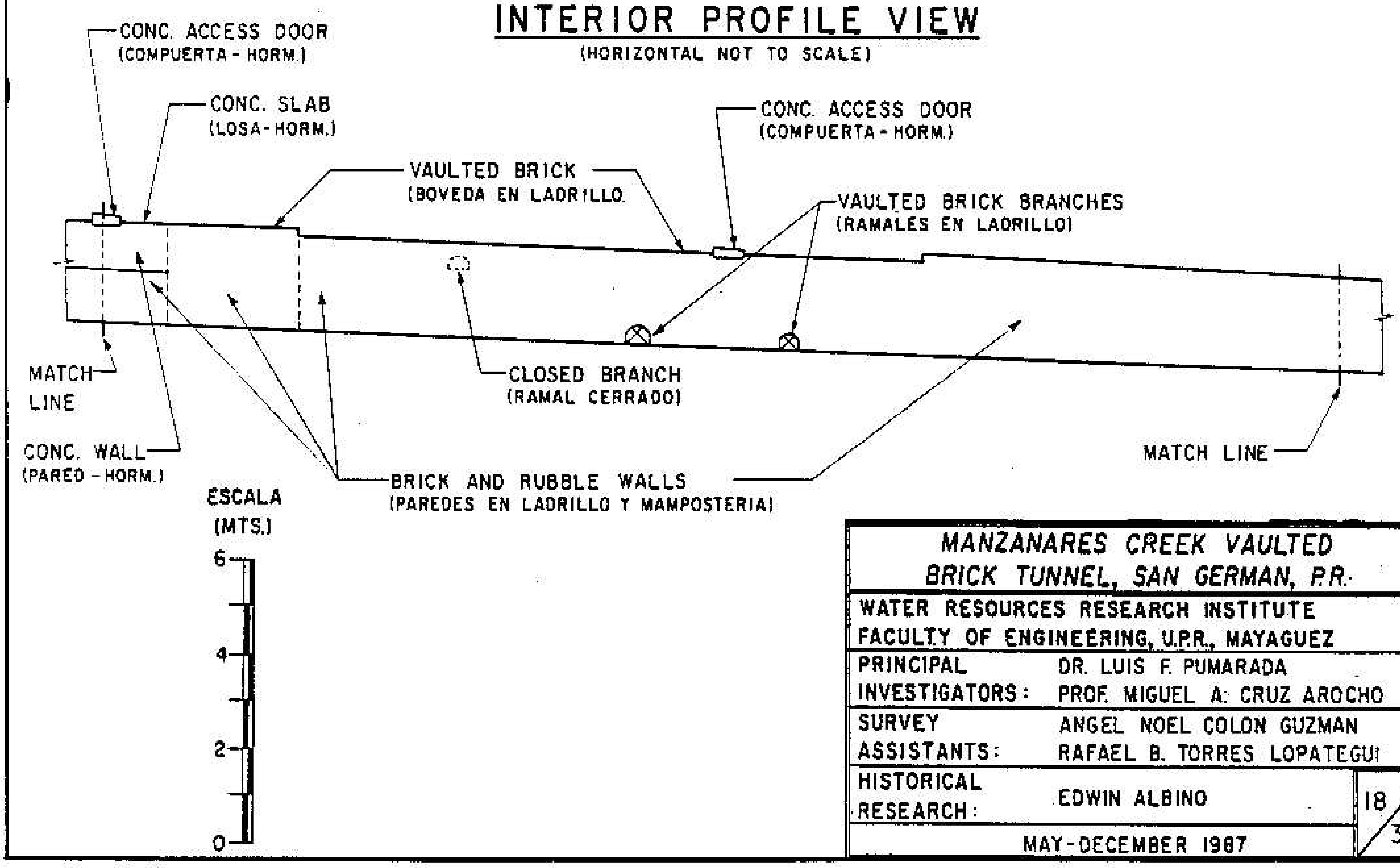
17/30

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

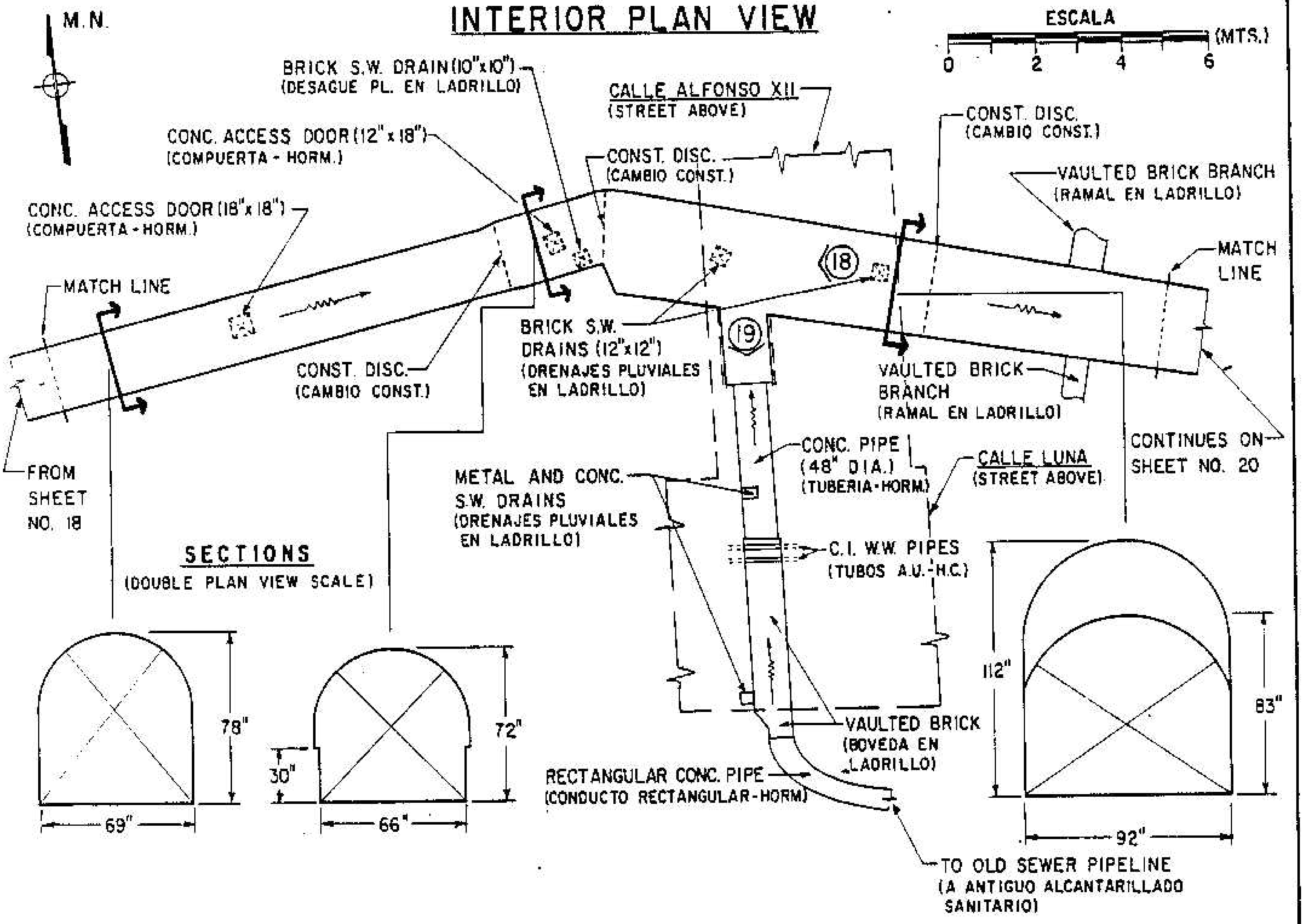
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

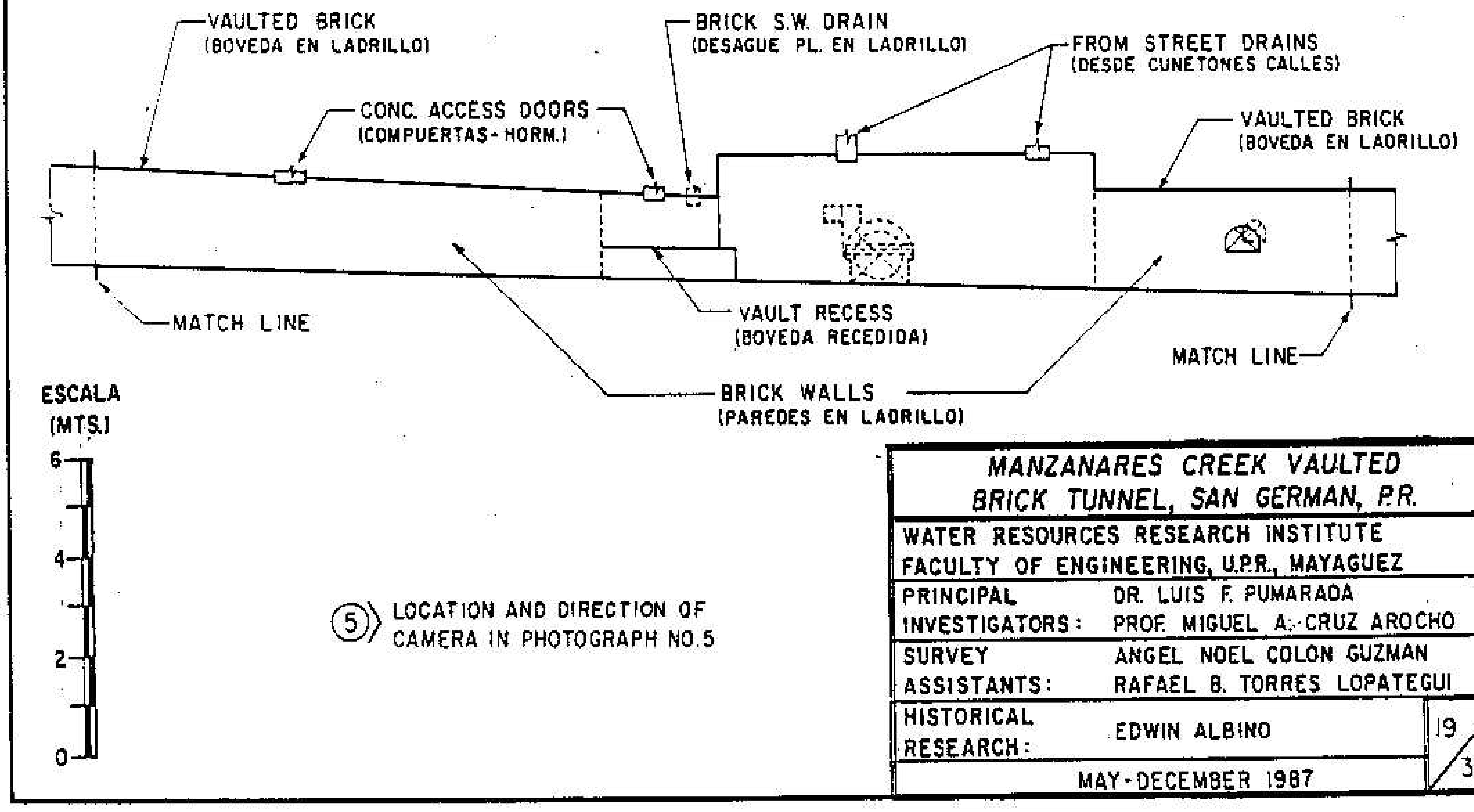
18/30

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO.5

MANZANARES CREEK VAULTED BRICK TUNNEL, SAN GERMAN, P.R.

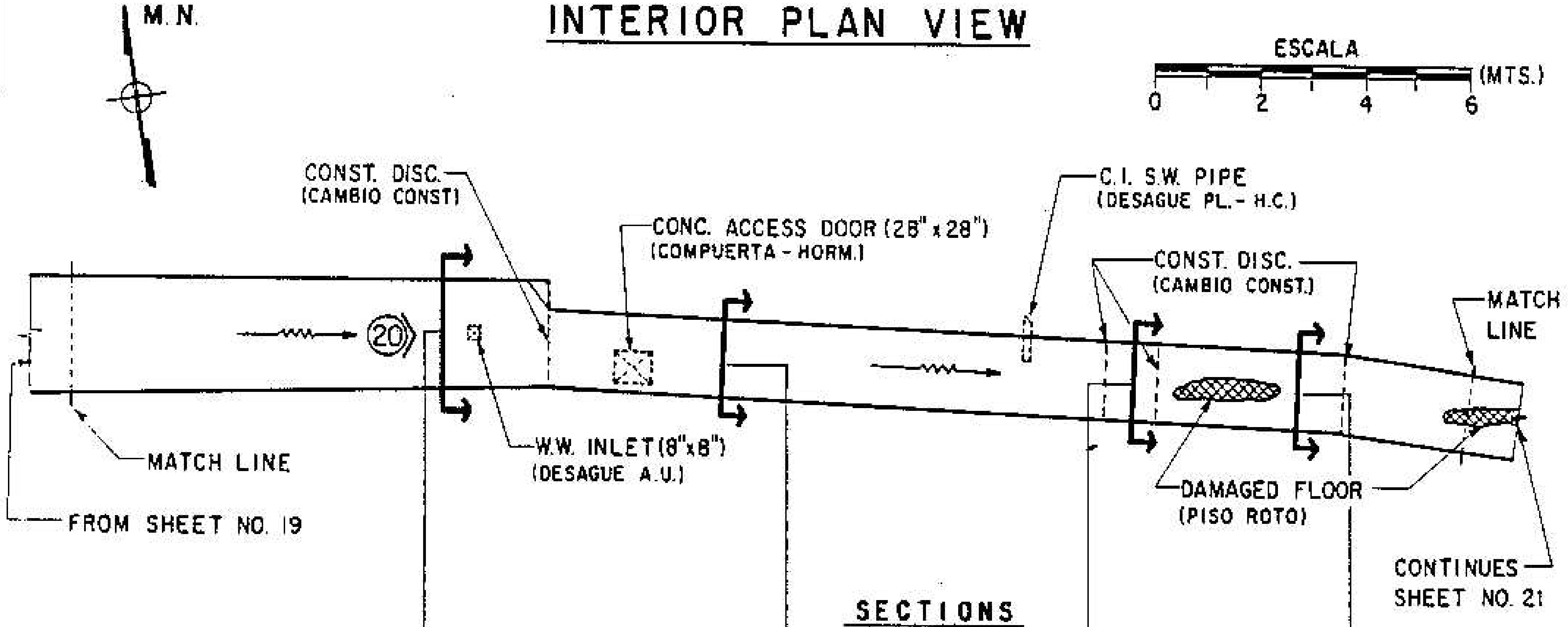
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

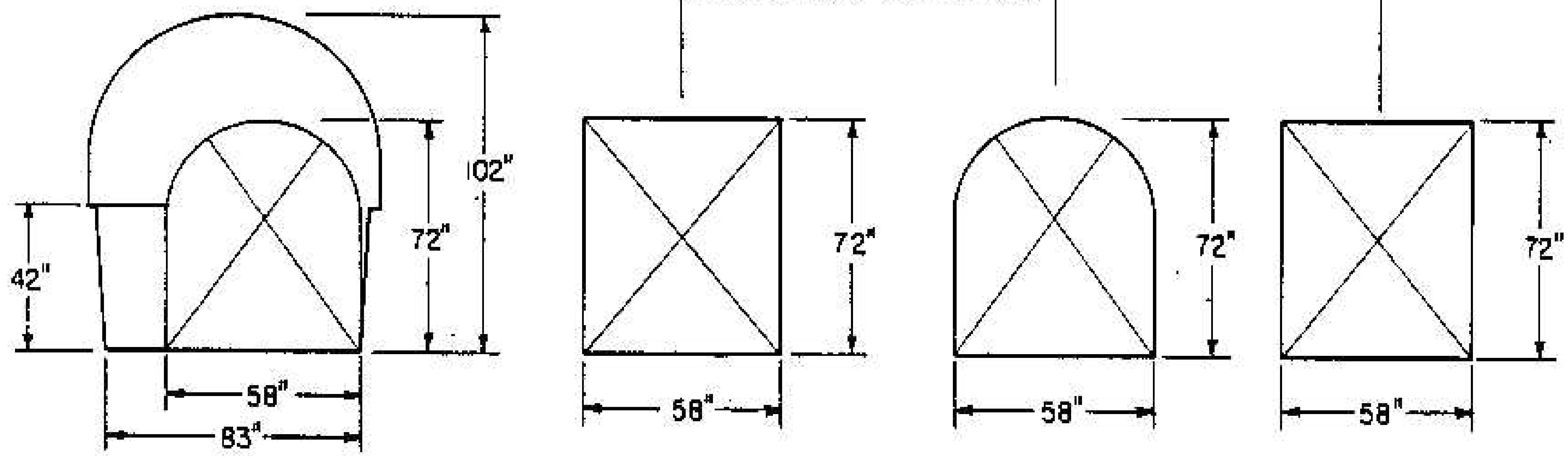
19/30

INTERIOR PLAN VIEW



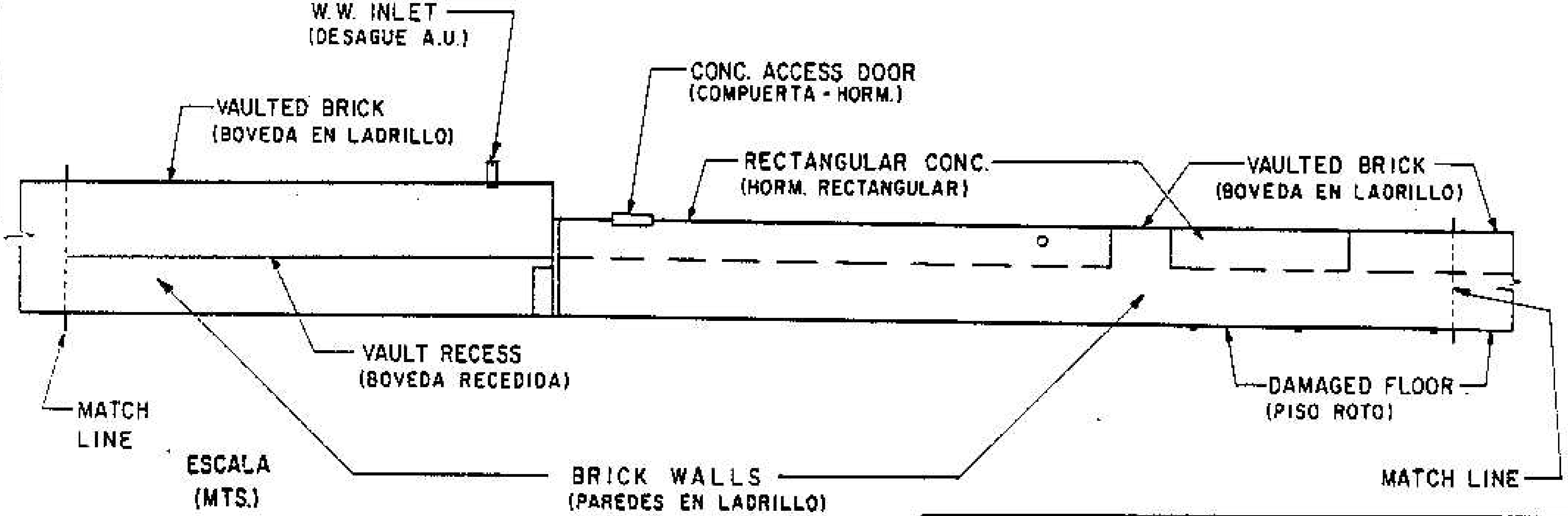
SECTIONS

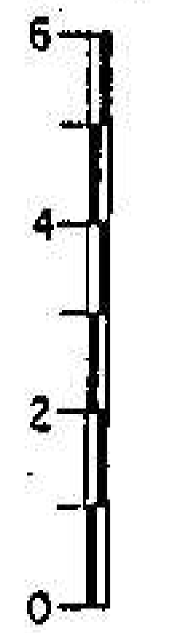
(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

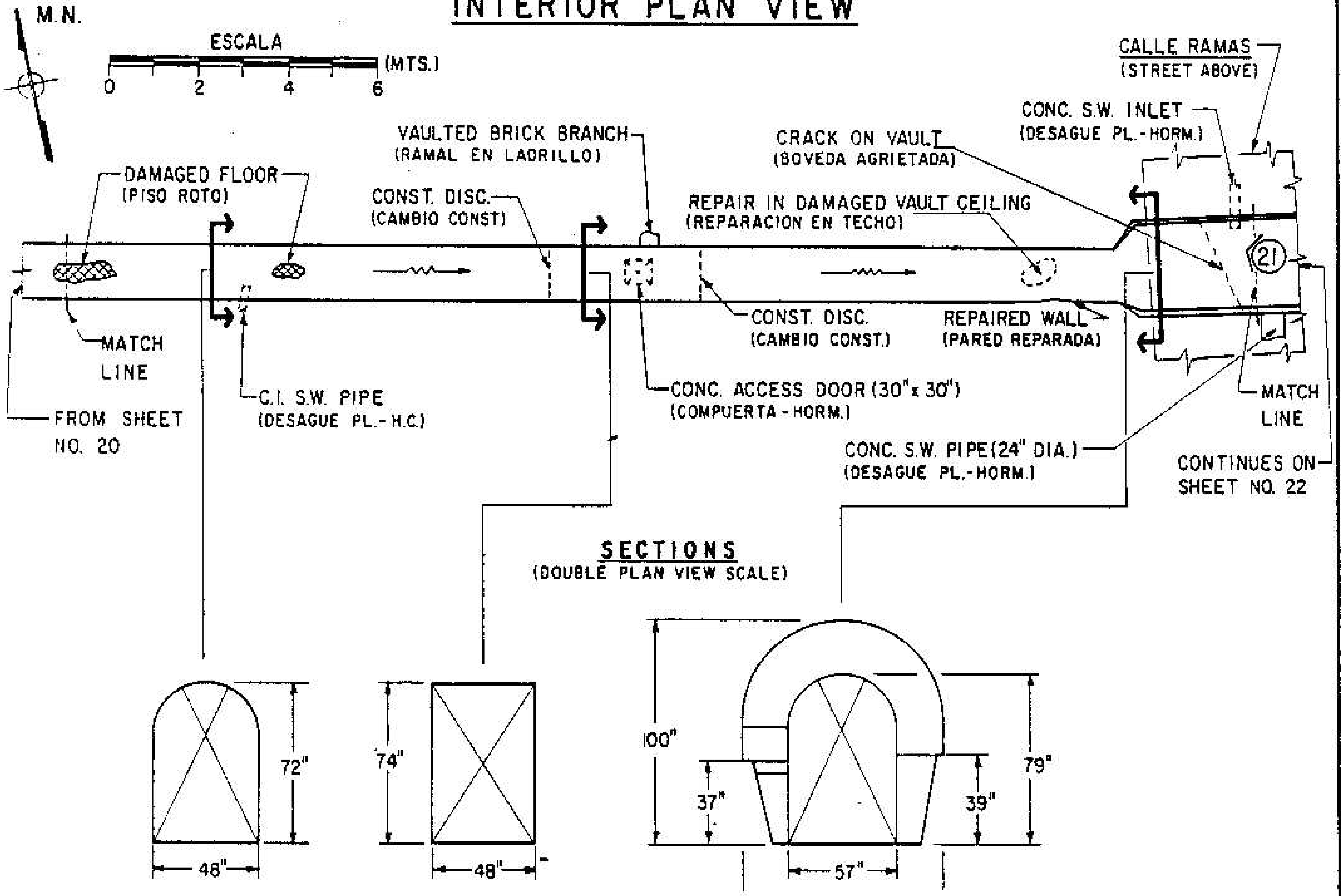
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

20/30

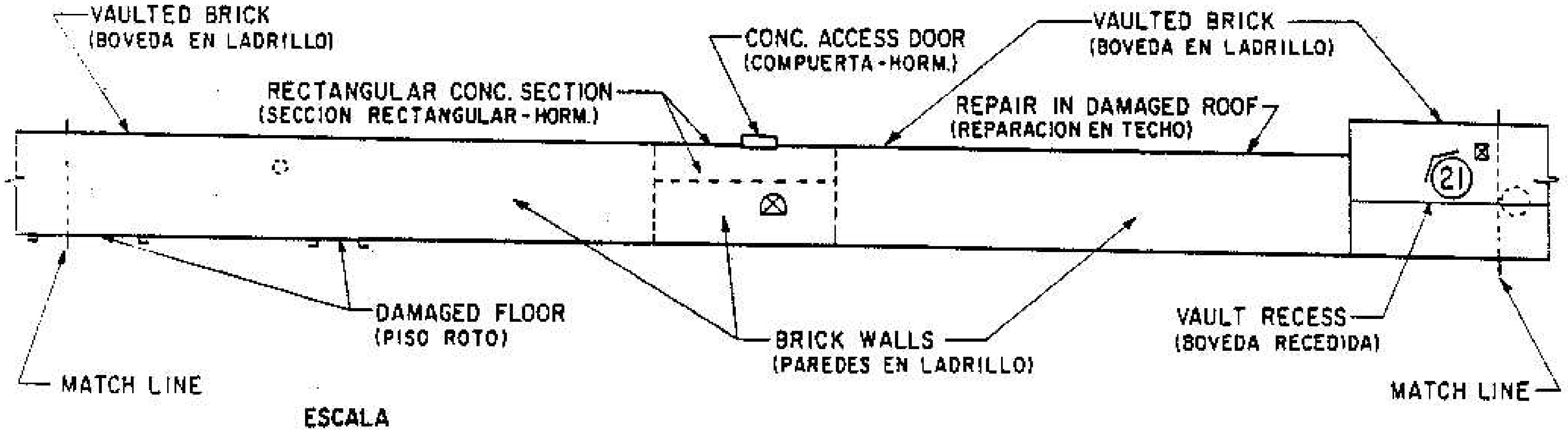
MAY-DECEMBER 1987

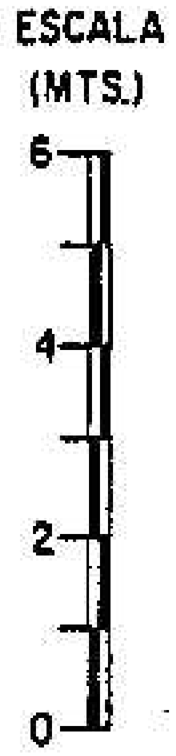
INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

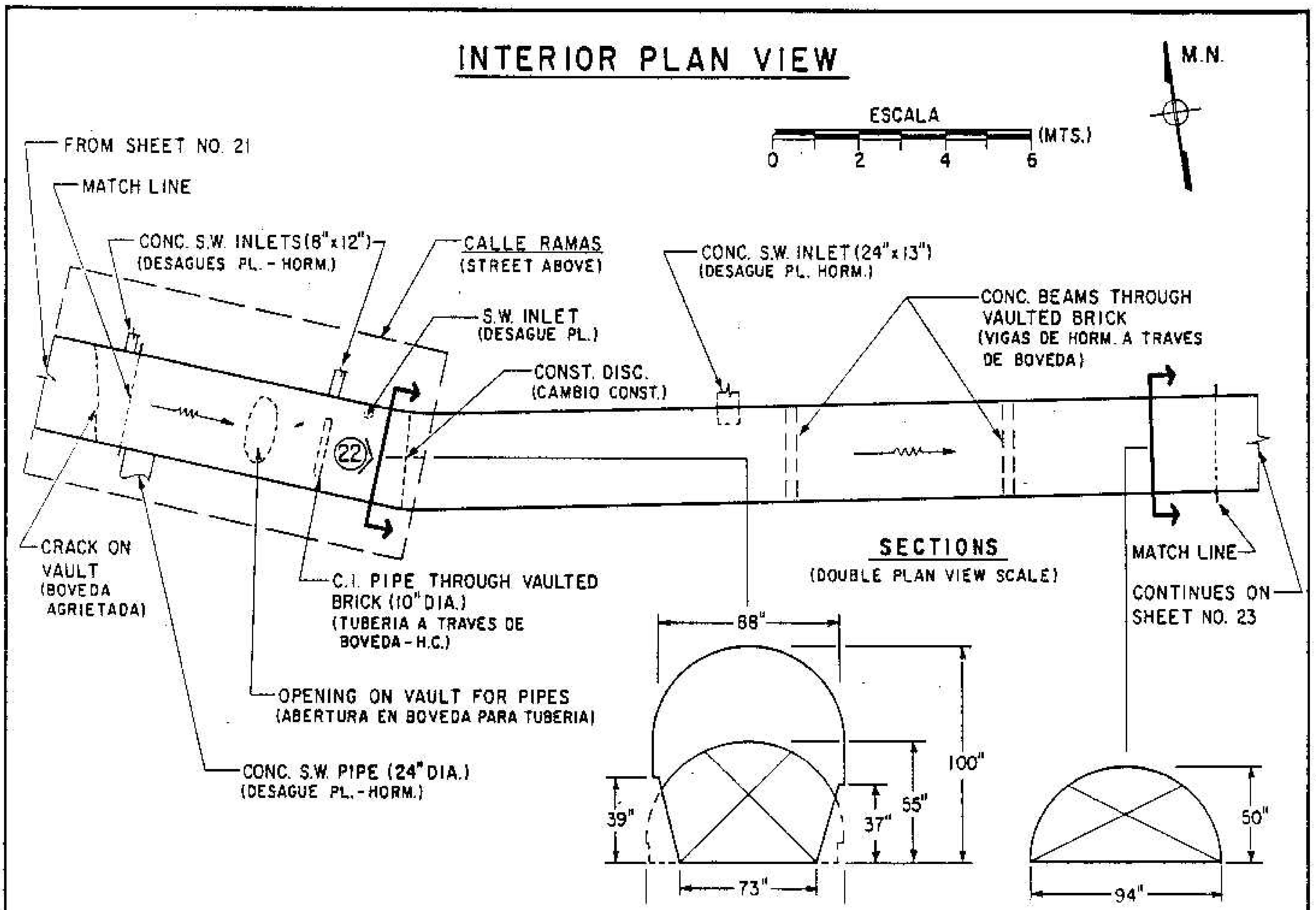
MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

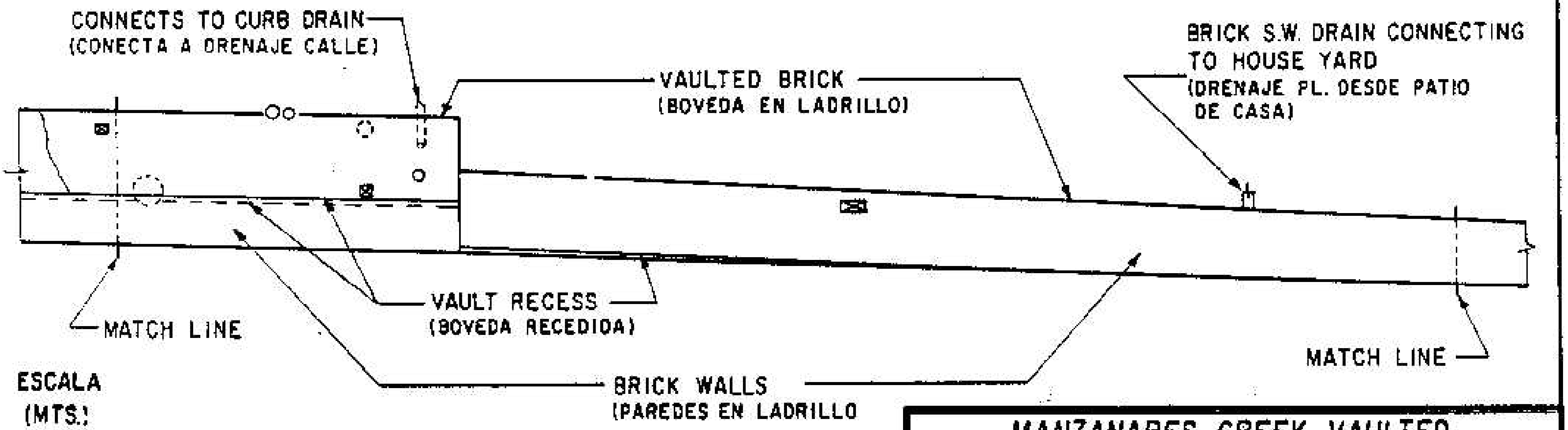
MAY-DECEMBER 1987

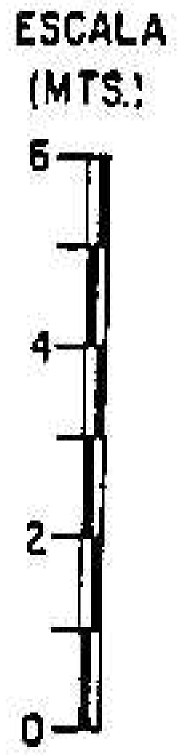
INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

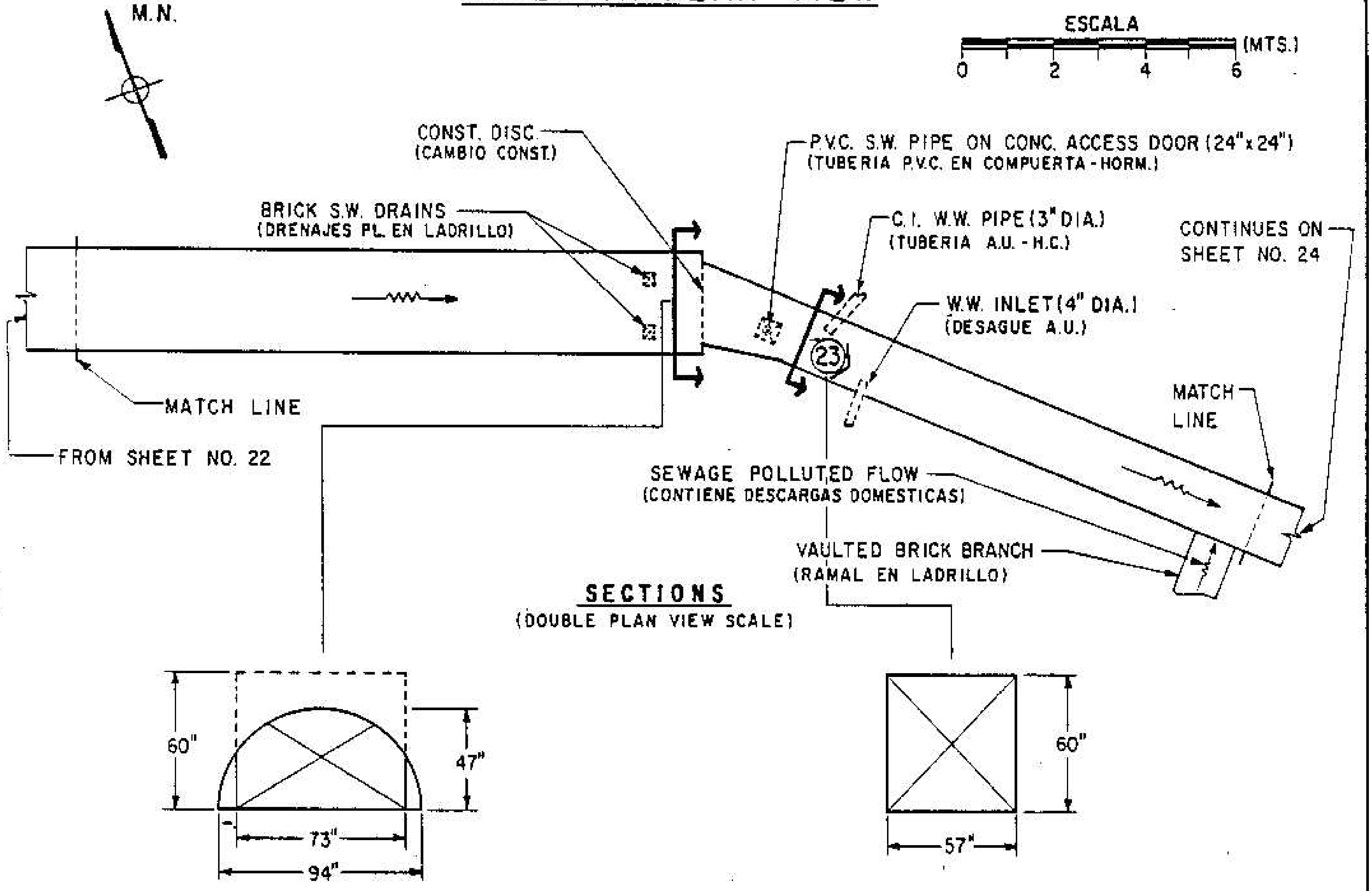
MANZANARES CREEK VAULTED BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

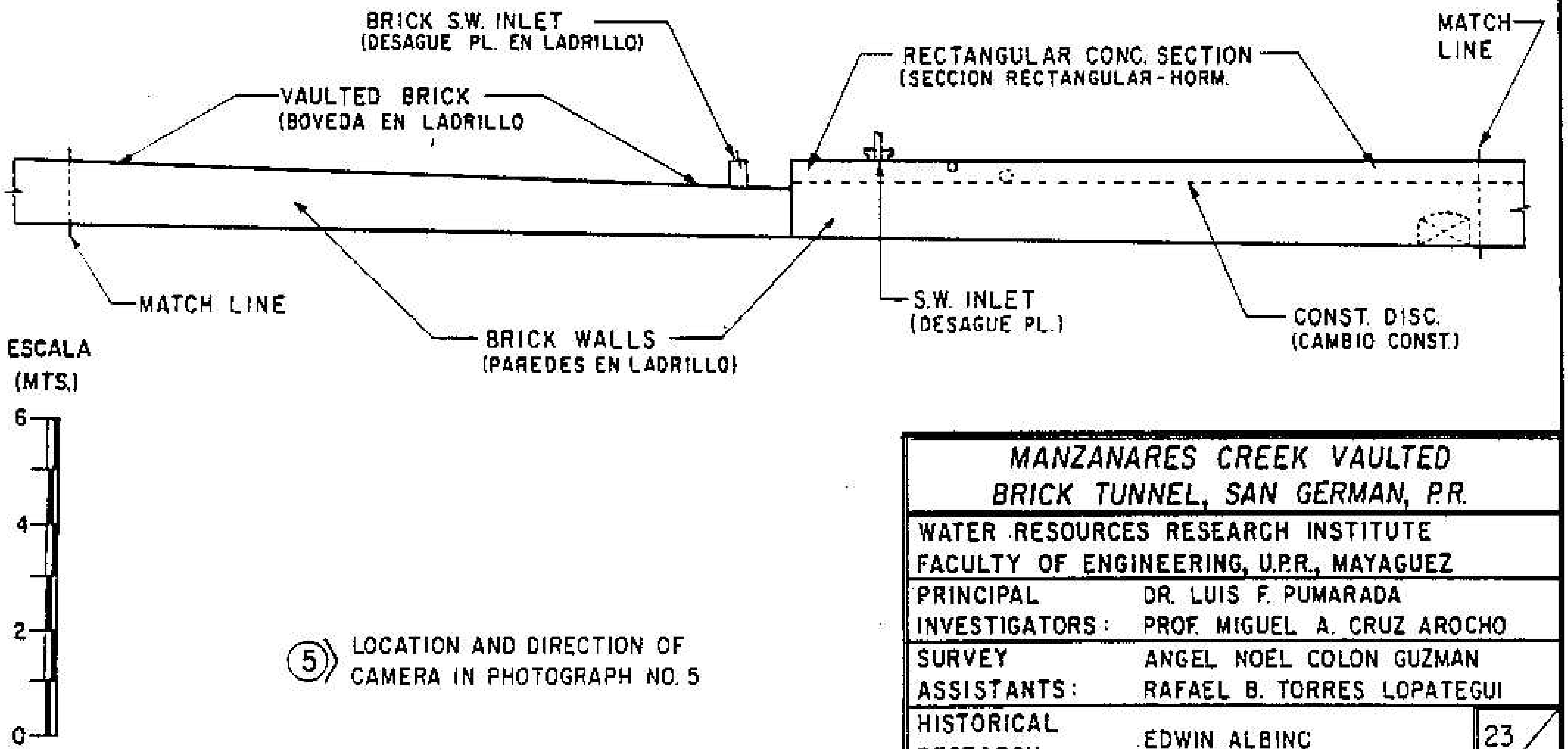
MAY-DECEMBER 1987

INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



⑤ LOCATION AND DIRECTION OF CAMERA IN PHOTOGRAPH NO. 5

MANZANARES CREEK VAULTED BRICK TUNNEL, SAN GERMAN, P.R.

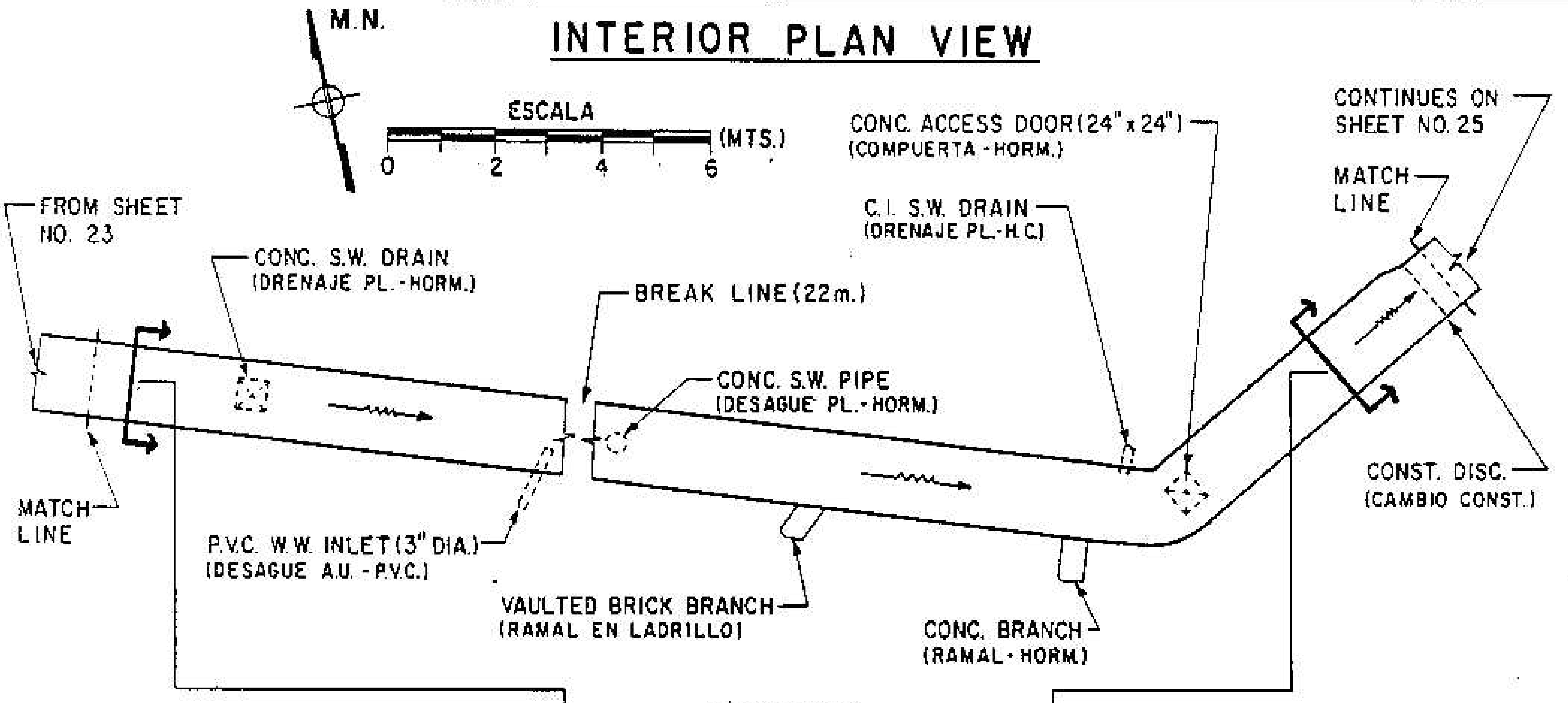
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

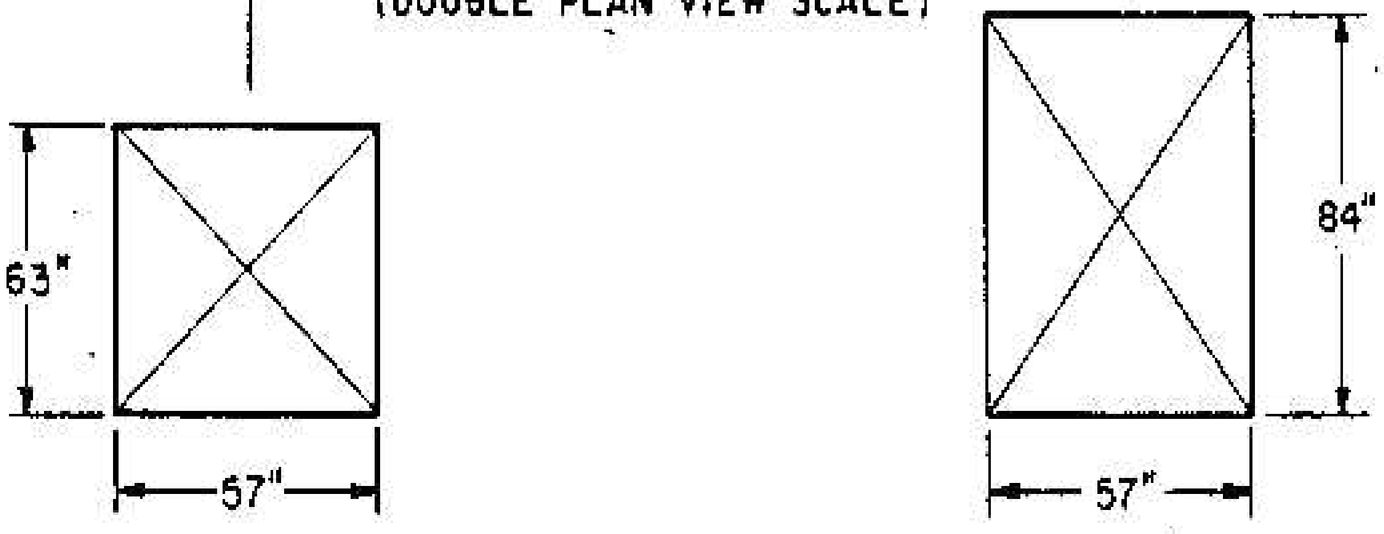
23/30

INTERIOR PLAN VIEW



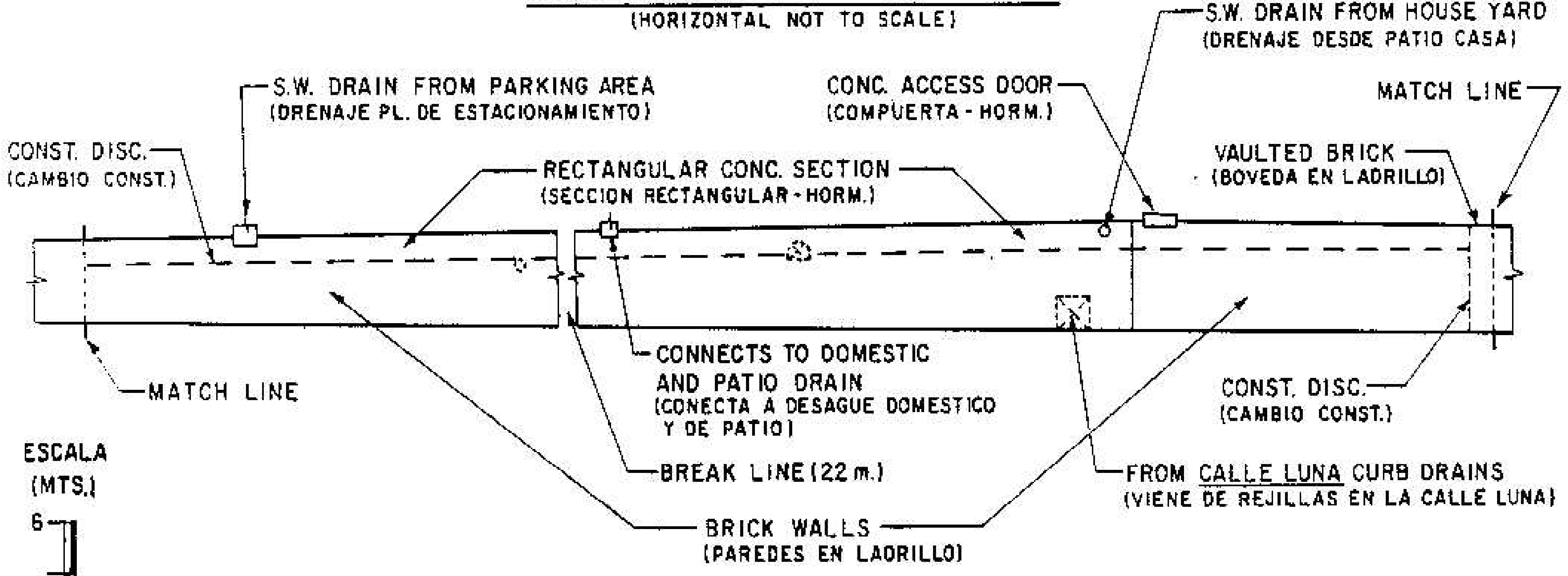
SECTIONS

(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)



MANZANARES CREEK VAULTED BRICK TUNNEL, SAN GERMAN, P.R.

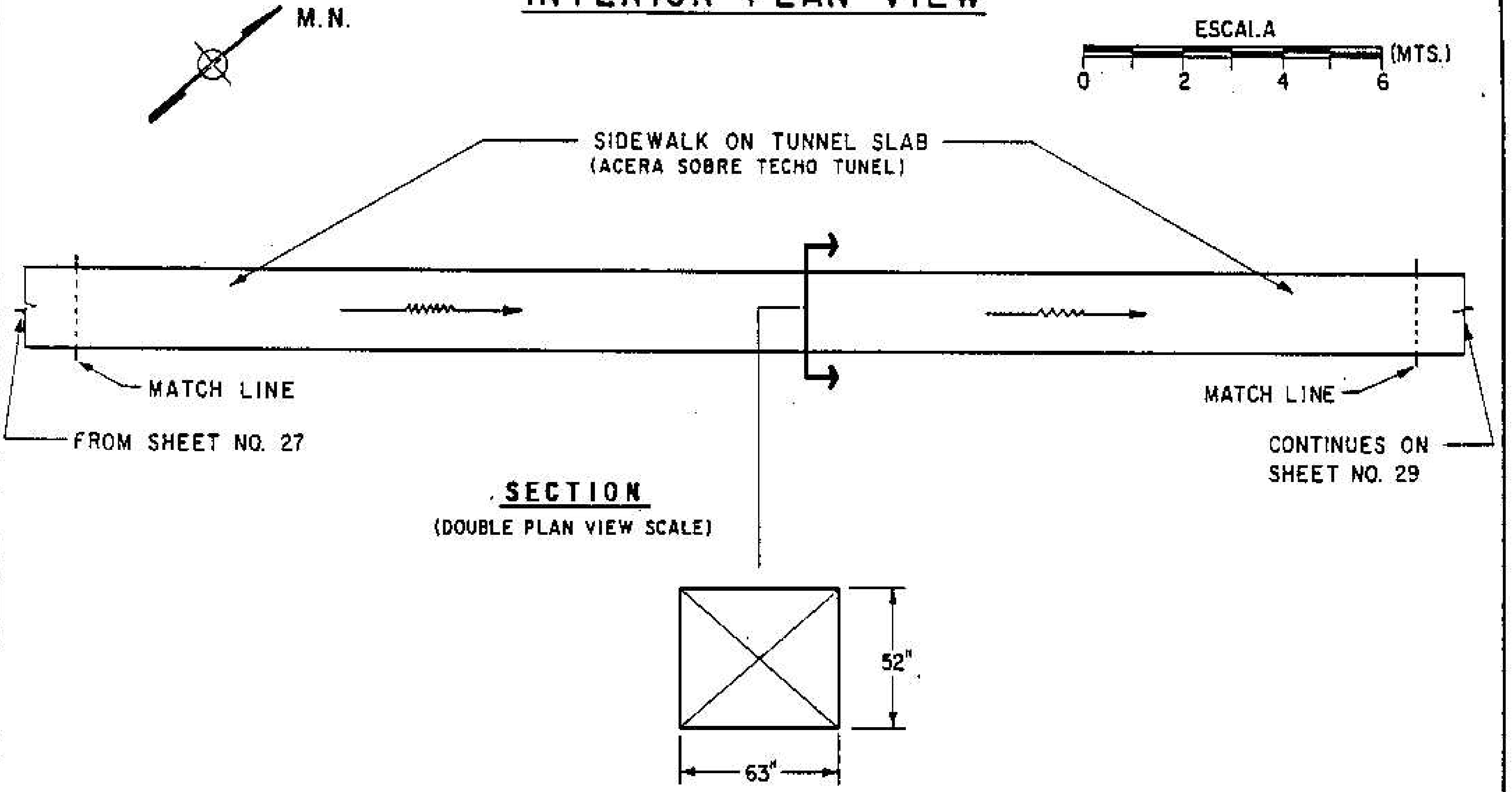
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

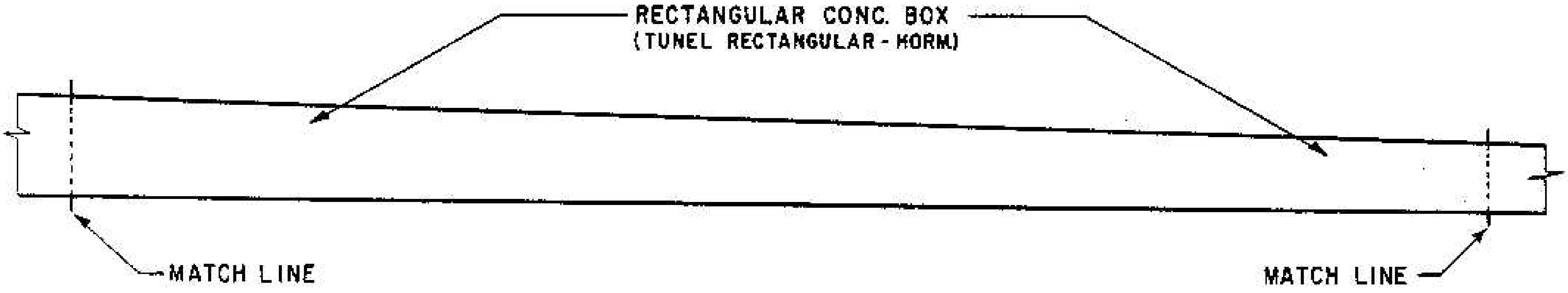
24/30

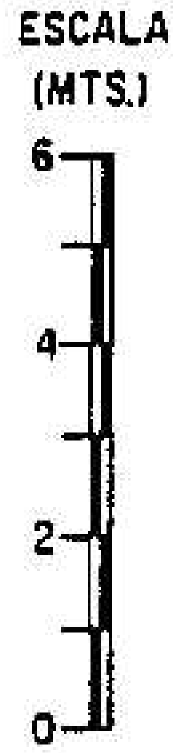
INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

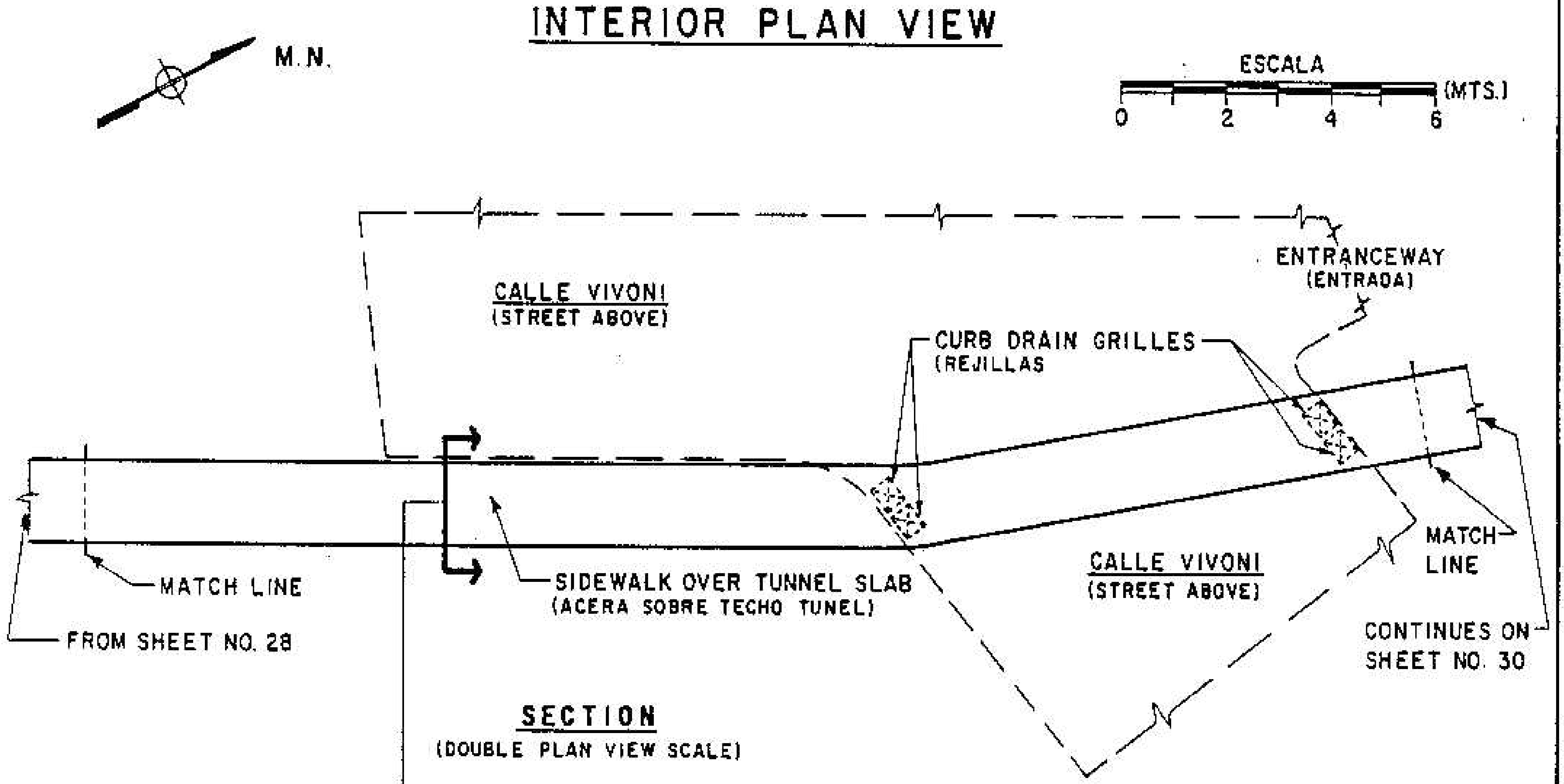
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON-GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

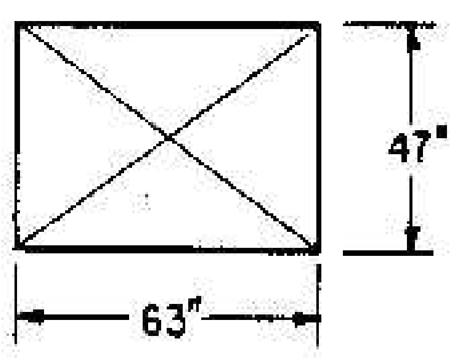
28/30

INTERIOR PLAN VIEW



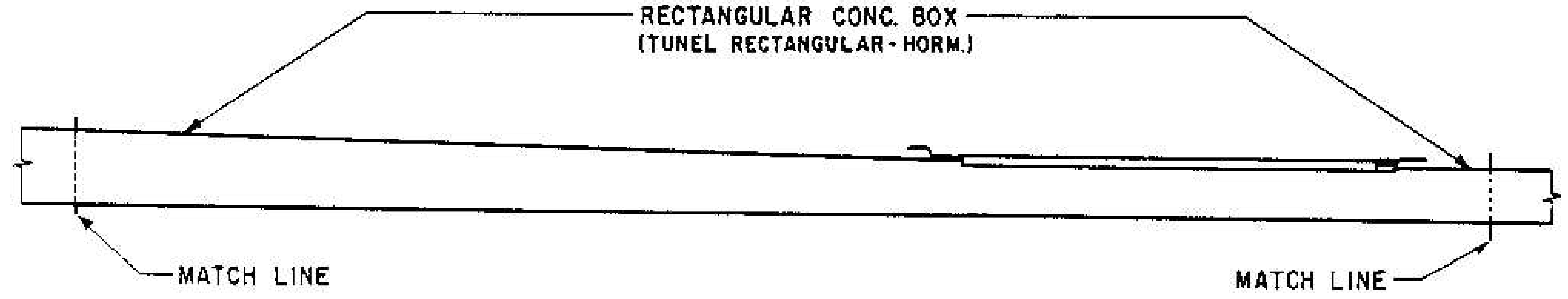
SECTION

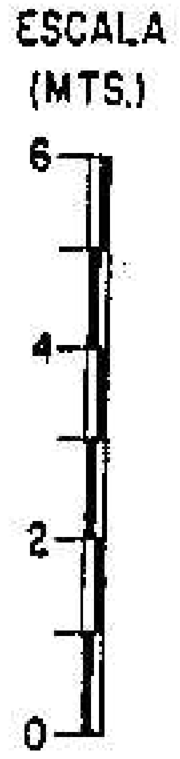
(DOUBLE PLAN VIEW SCALE)



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

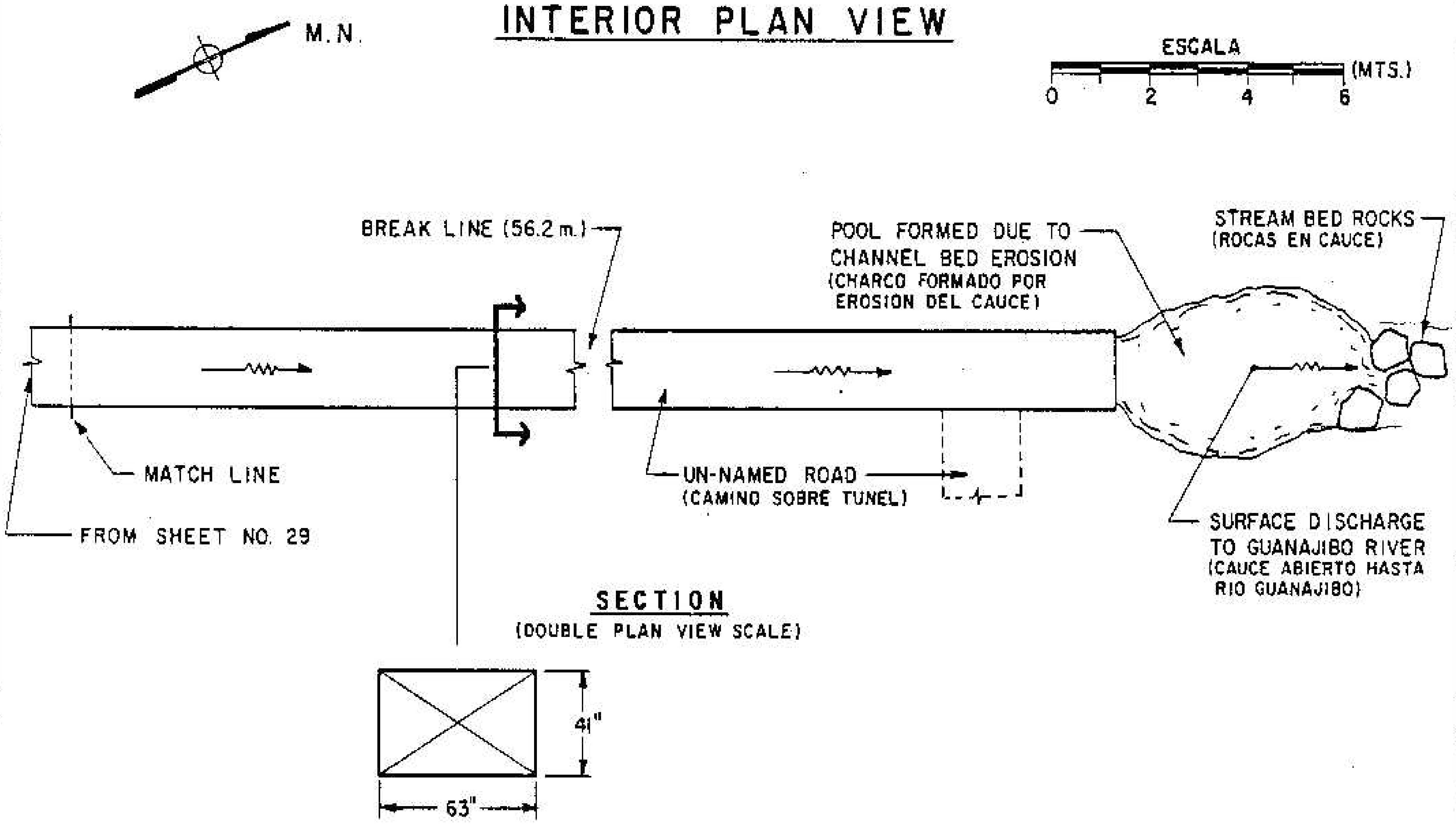
WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987

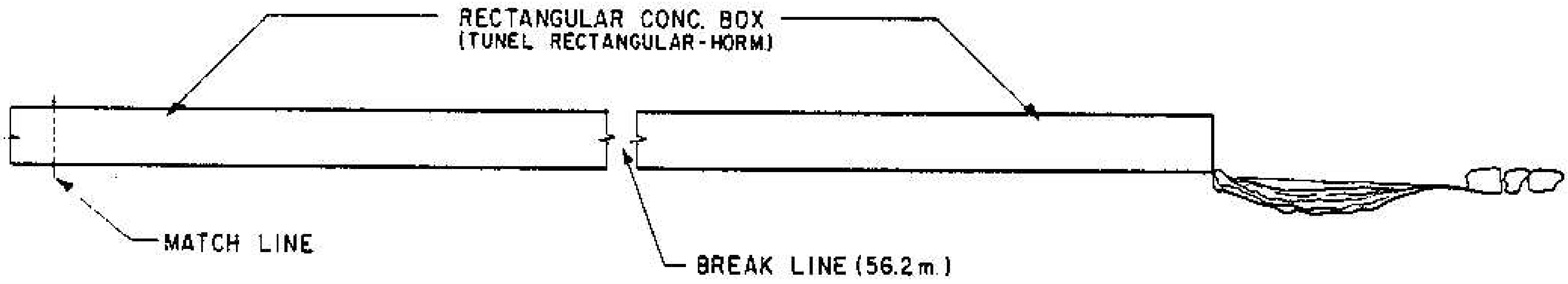
29/30

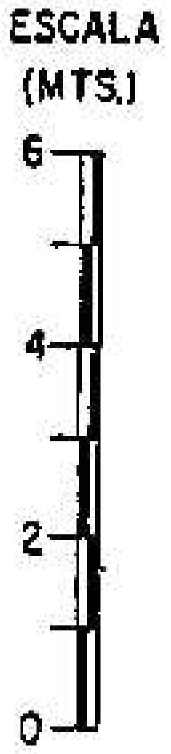
INTERIOR PLAN VIEW



INTERIOR PROFILE VIEW

(HORIZONTAL NOT TO SCALE)





MANZANARES CREEK VAULTED
BRICK TUNNEL, SAN GERMAN, P.R.

WATER RESOURCES RESEARCH INSTITUTE
FACULTY OF ENGINEERING, U.P.R., MAYAGUEZ

PRINCIPAL INVESTIGATORS:	DR. LUIS F. PUMARADA PROF. MIGUEL A. CRUZ AROCHO
SURVEY ASSISTANTS:	ANGEL NOEL COLON GUZMAN RAFAEL B. TORRES LOPATEGUI
HISTORICAL RESEARCH:	EDWIN ALBINO

MAY-DECEMBER 1987