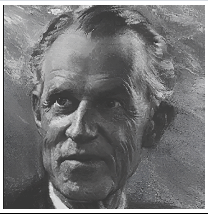

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REVISTA IRC - Revista do Instituto Roy Carlson

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Medindo a Temperatura e Sentindo o Pulso da Barragem de Ensaio no Stevenson Creek

Taking the Temperature and Feeling the Pulse of the Test Dam on Stevenson Creek

R. W. Carlson

Tradução: Flávio Mamede Pereira Gomes

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arch dam / barragem em arco, Stevenson Creek, telemeter / telêmetro, strain gauge / extensômetro, instrumentation / instrumentação, Engineering Foundation.

Sumário
Relato bilíngue (PT/EN) sobre a barragem experimental em arco do Stevenson Creek: instrumentação com telêmetros, extensômetros e clinômetros, e primeiras observações de movimentos térmicos — tradução de Flávio Mamede Pereira Gomes.

ENGLISH

Until recent years, arch dams have been designed in a very elementary way. The concrete has been assumed to carry loads without being deflected or strained and the arch has been treated as a portion of a rigid cylinder. The method for calculating the thickness of an arch section for assigned conditions has been too simple to be fascinating.

PORTUGUÊS

Até anos recentes, as barragens em arco foram projetadas de maneira muito elementar. Supunha-se que o concreto resistia às cargas sem sofrer deflexão nem deformação, e o arco era tratado como uma porção de um cilindro rígido. O método para calcular a espessura de uma seção de arco, dadas certas condições, era simples demais para ser fascinante.

Increasing knowledge about concrete and increasing investments in arch dams has brought a flood of refinements in design. All of these refinements have been required in recognition of the well-known fact that concrete deforms. Perhaps the first of these has been to take account of the effect of temperature changes on the length and shape of the concrete arch. The second has been to include the effect of shortening and bending of the concrete arch under the water load. Next has been to compute the load carried by the vertical beam sections and reduce the load to be carried by the horizontal arch sections by this amount. Other refinements have been the analysis of the effect of lateral expansion due to load, the effect of shear, the effect of shrinkage, the effect of moisture absorption, and other important but very uncertain conditions.

O crescente conhecimento sobre o concreto e os crescentes investimentos em barragens em arco trouxeram uma enxurrada de refinamentos ao projeto. Todos esses refinamentos tornaram-se necessários em reconhecimento ao fato bem conhecido de que o concreto se deforma. Talvez o primeiro deles tenha sido levar em conta o efeito das variações de temperatura sobre o comprimento e a forma do arco de concreto. O segundo foi incluir o efeito do encurtamento e da flexão do arco de concreto sob a carga d'água. Em seguida, veio o cálculo da carga absorvida pelas seções verticais em viga e a redução, nesse mesmo montante, da carga a ser resistida pelas seções horizontais em arco. Outros refinamentos foram a análise do efeito da expansão lateral decorrente da carga, do efeito do cisalhamento, do efeito da retração, do efeito da absorção de umidade e de outras condições importantes, porém muito incertas.

Before new developments can be made standard practice, the magnitude and importance of the score of actions which shall determine rational design must be evaluated. Meanwhile, to insure safety and cover uncertainties, arch dams are presumably being built many times stronger than calculations demand.

Antes que novos desenvolvimentos possam tornar-se prática corrente, é preciso avaliar a magnitude e a importância do conjunto de ações que haverão de determinar um projeto racional. Enquanto isso, para garantir a segurança e cobrir as incertezas, as barragens em arco vêm sendo construídas, presumivelmente, muitas vezes mais resistentes do que os cálculos exigem.

Realizing the certain gain in knowledge and economy which will accrue, the Engineering Foundation is sponsoring a full-sized test-to-destruction of a concrete arch dam. The site is located in the steep canyon of Stevenson Creek in the Sierra Nevada Mountains sixty miles east of Fresno, California, where the storage of water will be small and no damage can result from the ultimate failure.

Reconhecendo o ganho certo em conhecimento e economia que daí advirá, a Engineering Foundation patrocina um ensaio até a ruptura, em escala real, de uma barragem em arco de concreto. O local situa-se no íngreme desfiladeiro do Stevenson Creek, na Serra Nevada, a sessenta milhas (~97 km) a leste de Fresno, Califórnia, onde o volume de água armazenado será pequeno e nenhum dano poderá resultar da ruína final.

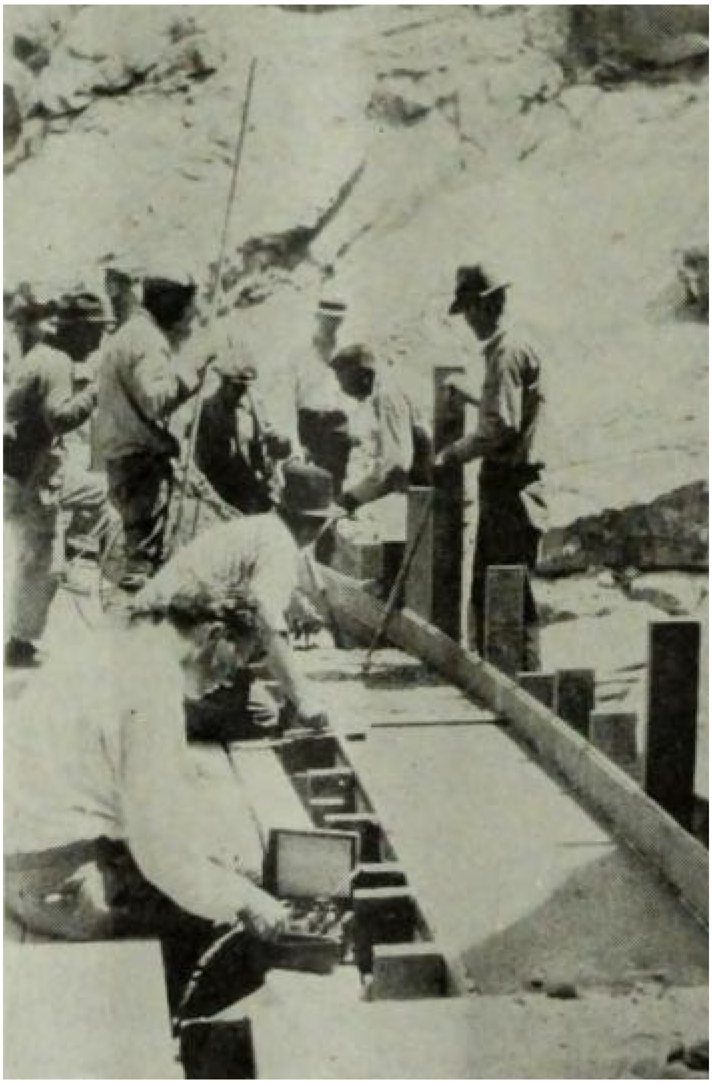


Figure 1 / Figura 1

Above: Author reading a telemeter, one of the many instruments used in the Engineering Foundation Dam.

Acima: O autor fazendo a leitura de um telêmetro, um dos muitos instrumentos utilizados na Barragem da Engineering Foundation.

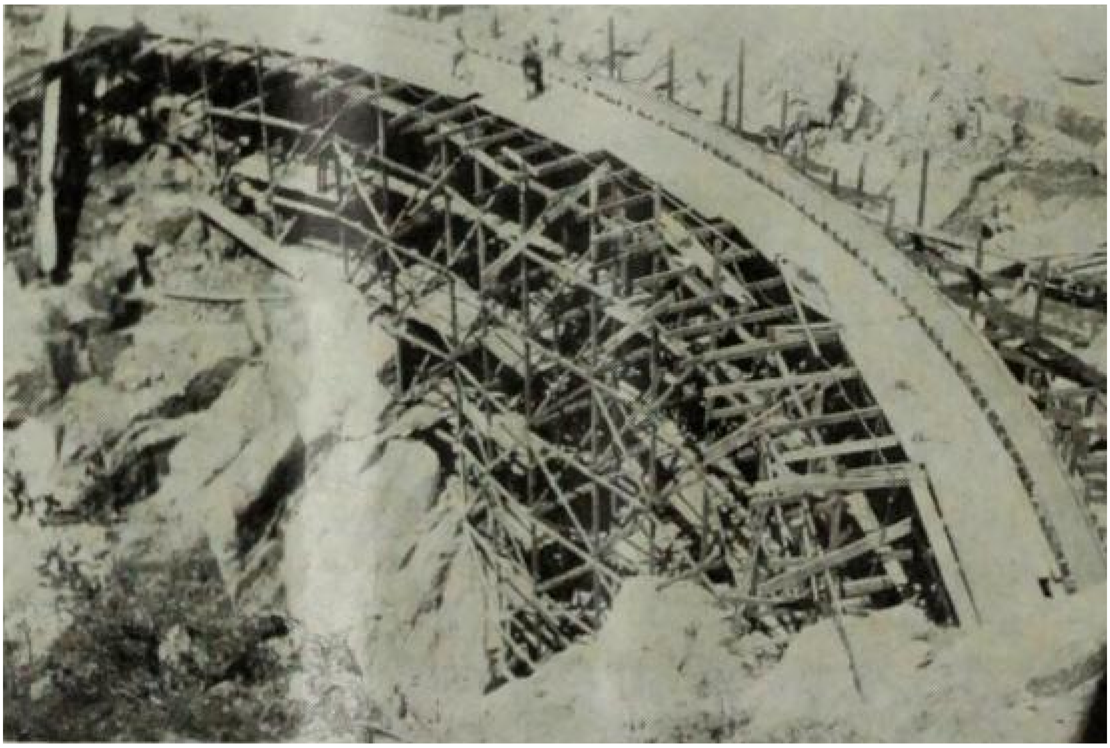


Figure 2 / Figura 2

Below: The completed dam before the forms were removed.

Abaixo: A barragem concluída, antes da retirada das formas.

The dam has been completed to a height of sixty feet and will be tested extensively before being built higher. It is an unreinforced single arch of 140 foot crest length, 100 feet radius, seven and one-half foot thickness at the base, two foot thickness at the thirty foot level, with no change in thickness from that level to the crest. The abutments make angles of forty-five degrees with the horizontal on either side of the canyon, and the central portion of the foundation is a vertical arc of twenty-five foot radius. The concrete is uniform throughout and numerous tests of samples indicate that it is capable of supporting more than two thousand pounds per square inch.

A barragem foi concluída até uma altura de sessenta pés (~18 m) e será extensamente ensaiada antes de ser elevada. Trata-se de um arco simples, não armado, com 140 pés (~43 m) de comprimento de crista, 100 pés (~30 m) de raio, sete pés e meio (~2,3 m) de espessura na base e dois pés (~0,61 m) de espessura na cota de trinta pés (~9 m), sem variação de espessura dessa cota até a crista. As ombreiras formam ângulos de quarenta e cinco graus com a horizontal, de cada lado do desfiladeiro, e a porção central da fundação é um arco vertical de vinte e cinco pés (~7,6 m) de raio. O concreto é uniforme em toda a sua extensão, e numerosos ensaios de amostras indicam que ele é capaz de resistir a mais de duas mil libras por polegada quadrada (~13,8 MPa).

1. Meters and Gauges

Since the distribution of stresses depends upon deformations of the concrete, elaborate preparation is made for measuring the minute internal and external movements. To measure extension or shortening, five hundred ten-inch distances (between steel plugs systematically located on the surfaces of the dam) are measured from time to time to a ten thousandth of an inch with strain gauges. The change in inclination of the downstream face of the dam are measured at sixty stations to a thousandth of an inch in five feet by a five foot vertical clinometer. The changes in curvature of the horizontal arch sections are measured at some fifty stations by means of an especially designed change-of-radius meter. The movements of central portions of the dam upstream or downstream are measured from the sides of the canyon by means of surveyors' theodolites with telescopes of high power. Measurements are to be made to detect tilting of the foundation at five stations by placing an especially designed level bar on heavy I-beams anchored and grouted in the rock. Separation of the dam from the foundation at some points has already been found by measuring gauge lines spanning from the foundation to the dam. Internal distortions and temperatures are measured by 140 carbon resistor strain gauges (known as telemeters) buried in the concrete.

2. Medidores e Extensômetros

Como a distribuição das tensões depende das deformações do concreto, faz-se uma elaborada preparação para medir os diminutos movimentos internos e externos. Para medir o alongamento ou o encurtamento, quinhentas distâncias de dez polegadas (~254 mm) — entre pinos de aço sistematicamente dispostos nas superfícies da barragem — são medidas de tempos em tempos, com aproximação de um décimo de milésimo de polegada (~2,5 µm), por meio de extensômetros. A variação da inclinação da face de jusante da barragem é medida em sessenta estações, com aproximação de um milésimo de polegada em cinco pés (~25 µm em 1,5 m), por meio de um clinômetro vertical de cinco pés (~1,5 m). As variações da curvatura das seções horizontais em arco são medidas em cerca de cinquenta estações, por meio de um medidor de variação de raio especialmente projetado. Os movimentos das porções centrais da barragem, para montante ou para jusante, são medidos a partir das encostas do desfiladeiro, com teodolitos de agrimensor dotados de lunetas de grande aumento. Serão feitas medições para detectar o basculamento da fundação em cinco estações, dispondo-se uma barra de nível especialmente projetada sobre pesadas vigas I ancoradas e chumbadas na rocha. A separação entre a barragem e a fundação, em alguns pontos, já foi constatada pela medição de linhas de referência que se estendem da fundação à barragem. As distorções e temperaturas internas são medidas por 140 extensômetros de resistência de carbono (conhecidos como telêmetros) embutidos no concreto.

From the data obtained by the various instruments, all types of movements can be determined and checked. Both vertical and horizontal bending of the arch can be computed independently from data from the vertical clinometer, the change-of-radius meter, and the telemeters. Movements of the central portion of the dam as a body can be obtained directly by the theodolites and vertical clinometers and checked by the telemeters, strain gauges, and change-of-radius meters. Total tensile and compressive strains, independent of bending, can be measured by the strain gauges and telemeters.

A partir dos dados obtidos pelos diversos instrumentos, todos os tipos de movimento podem ser determinados e conferidos. Tanto a flexão vertical quanto a horizontal do arco podem ser calculadas de forma independente, a partir dos dados do clinômetro vertical, do medidor de variação de raio e dos telêmetros. Os movimentos da porção central da barragem, como corpo, podem ser obtidos diretamente pelos teodolitos e clinômetros verticais e conferidos pelos telêmetros, pelos extensômetros e pelos medidores de variação de raio. As deformações totais de tração e de compressão, independentes da flexão, podem ser medidas pelos extensômetros e telêmetros.

3. How the Telemeter Works

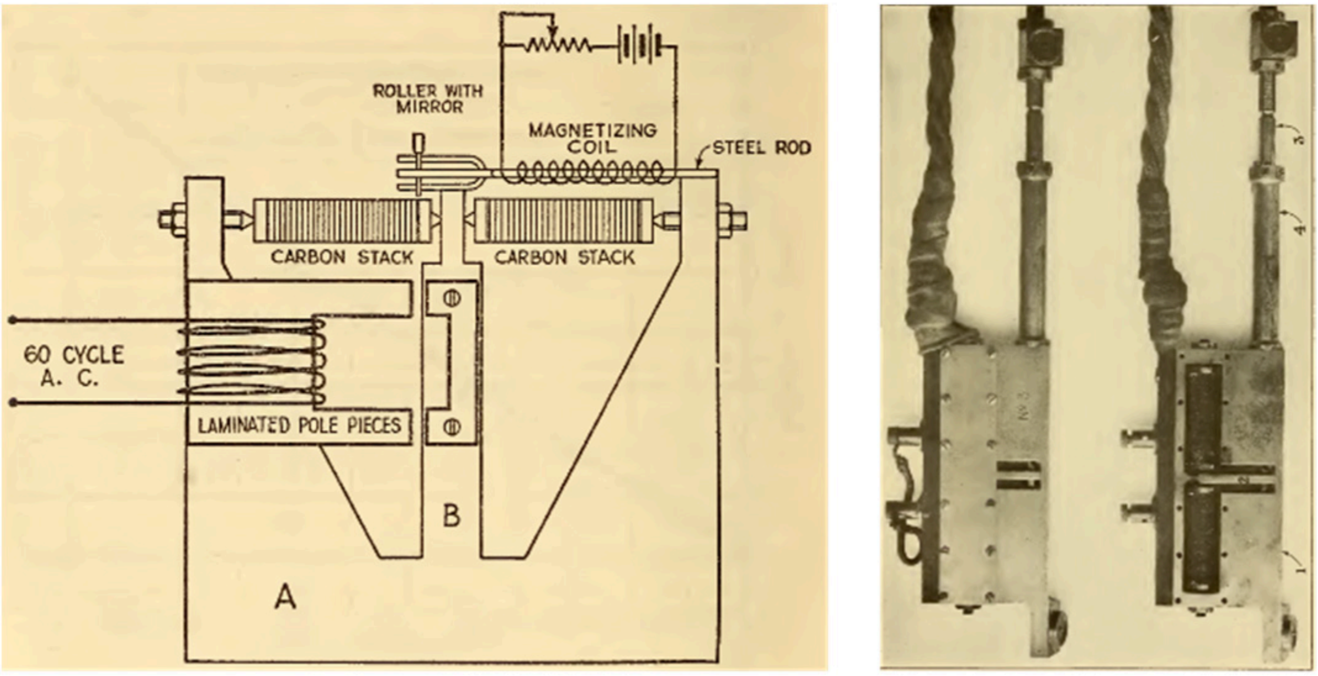
The telemeters are a product of the United States Bureau of Standards and are a relatively recent invention. Each telemeter consists essentially of a stack of carefully prepared carbon rings supported between two end-pieces of steel. The stack is protected by a collar of steel which does not interfere with the movement of the end pieces. Electrical leads from without the cartridge are connected to the two ends of the carbon stack. When the end pieces are brought closer together, the contact between the carbon rings is improved and an electrical current flows more readily. Having once calibrated a telemeter, it is a simple matter to detect any relative movement of the end pieces by measuring the ease with which an electric current flows through the stack. When a telemeter is buried, the end pieces are bonded to the concrete and any internal movement in the concrete affects the distance between them and consequently affects the electrical resistance of the stack. As small a movement as two millionths of an inch per inch of length can be detected with some certainty. In fact, in the experimental dam, the free expansion or contraction due to the change in temperature which occurs in a few minutes has definitely been obtained.

The experimental dam is built with a very small factor of safety. With the reservoir filled, it would be unsafe to make measurements on the downstream face without knowing something of the stresses in the concrete. It is here that the telemeters have an added utility of great importance. For they are wired to a control station above the dam where there is no danger. Enough readings can be made and interpreted in a few minutes times to show with some assurance whether or not the dam is safe. If it is safe, observers can obtain readings of all instruments. If it is not safe, readings of the telemeters can be taken without danger until the very time that the dam bursts. These are the readings which reveal the greatest differences between calculated behavior and actual behavior and are therefore of utmost value.

4. Como Funciona o Telêmetro

Os telêmetros são um produto do Bureau de Padrões dos Estados Unidos e constituem uma invenção relativamente recente. Cada telêmetro consiste, essencialmente, em uma pilha de anéis de carbono cuidadosamente preparados, apoiada entre duas peças de extremidade de aço. A pilha é protegida por um colar de aço que não interfere no movimento das peças de extremidade. Condutores elétricos, vindos de fora do cartucho, ligam-se às duas extremidades da pilha de carbono. Quando as peças de extremidade são aproximadas, o contato entre os anéis de carbono melhora e a corrente elétrica passa a fluir com mais facilidade. Uma vez calibrado o telêmetro, é tarefa simples detectar qualquer movimento relativo das peças de extremidade, medindo-se a facilidade com que a corrente elétrica atravessa a pilha. Quando o telêmetro é embutido, suas peças de extremidade ficam solidarizadas ao concreto, de modo que qualquer movimento interno no concreto altera a distância entre elas e, por consequência, altera a resistência elétrica da pilha. É possível detectar, com certa segurança, um movimento tão pequeno quanto dois milionésimos de polegada por polegada de comprimento (2×10^{-6}). De fato, na barragem experimental, já se obteve com nitidez a livre expansão ou contração devida à variação de temperatura que ocorre em poucos minutos.

A barragem experimental é construída com um fator de segurança muito pequeno. Com o reservatório cheio, seria arriscado fazer medições na face de jusante sem conhecer algo das tensões no concreto. É justamente aqui que os telêmetros têm uma utilidade adicional de grande importância, pois estão ligados por fios a uma estação de controle, situada acima da barragem, onde não há perigo. Em poucos minutos é possível fazer e interpretar leituras suficientes para indicar, com alguma segurança, se a barragem está ou não em condições seguras. Se estiver segura, os observadores podem obter as leituras de todos os instrumentos. Se não estiver, as leituras dos telêmetros podem ser tomadas sem perigo até o exato instante em que a barragem se rompa. São essas as leituras que revelam as maiores diferenças entre o comportamento calculado e o comportamento real e que, por isso, têm o máximo valor.



(a) (b)

Figure 3 / Figura 3 — Electrical telemeter (McCollum & Peters, 1924): (a) schematic; (b) closed and open packaging. After Glisic (2022), Fig. 6, citing McCollum & Peters, Technol. Pap. Bur. Stand. 1924.

Figure 3. Electrical telemeter of the Bureau of Standards type (carbon stack): (a) schematic; (b) closed and open packaging. Source: Glisic, B. (2022), Fig. 6, after McCollum & Peters (1924).

Figura 3. Telêmetro elétrico do tipo Bureau of Standards (pilha de carbono): (a) esquema; (b) invólucro fechado e aberto. Fonte: Glisic, B. (2022), Fig. 6, a partir de McCollum & Peters (1924).

5. Tests to Be Fruitful

The reservoir has not been filled as yet, but tests are being made regularly to study the effects of shrinkage, unequal heating, curing of the concrete, and other necessary items. It has been found that each morning when the sun begins to shine on the upstream face of the dam, the central portions begin to move upstream. The cracks between the abutments and the dam on the upstream side begin to close up, the pressure on the upstream toe of the lower portion of the foundation increases, while noticeable bending takes place throughout the dam. In the afternoon, the dam deflects downstream again and returns to its early morning position. The largest upstream movement observed in a single day has been a twentieth of an inch. On account of the movement while the sun is shining on the dam, it is necessary to make the principal observations between midnight and sunrise so that the results represent the equilibrium conditions of the dam.

The concordance between measurements with the various instruments is decidedly satisfactory. Every indication is that no large eccentricity of behavior of the arch will be missed. By pushing the test to the limit and being able to read distortions until the last minute, before failure, there is little question but that the tests will be fruitful.

6. Ensaios que Serão Frutíferos

O reservatório ainda não foi enchido, mas ensaios vêm sendo feitos regularmente para estudar os efeitos da retração, do aquecimento desigual, da cura do concreto e de outros itens necessários. Verificou-se que, a cada manhã, quando o sol começa a incidir sobre a face de montante da barragem, as porções centrais começam a se deslocar para montante. As fissuras entre as ombreiras e a barragem, no lado de montante, começam a se fechar; a pressão sobre o pé de montante da porção inferior da fundação aumenta, enquanto uma flexão perceptível ocorre por toda a barragem. À tarde, a barragem volta a defletir para jusante e retorna à sua posição do início da manhã. O maior deslocamento para montante observado em um único dia foi de um vigésimo de polegada (~1,3 mm). Por causa desse movimento enquanto o sol incide sobre a barragem, é necessário fazer as principais observações entre a meia-noite e o nascer do sol, para que os resultados representem as condições de equilíbrio da barragem.

A concordância entre as medições obtidas com os diversos instrumentos é francamente satisfatória. Tudo indica que nenhuma grande excentricidade de comportamento do arco passará despercebida. Levando o ensaio até o limite e podendo ler as distorções até o último minuto, antes da ruptura, há pouca dúvida de que os ensaios serão frutíferos.

7. Original publication / Publicação original (fac-símile)

Facsimile of Carlson’s article in *Modern Irrigation / Hydraulic Engineering*, July 1926, pp. 22 and 24 (public domain). / Fac-símile do artigo de Carlson em *Modern Irrigation / Hydraulic Engineering*, julho de 1926, pp. 22 e 24 (domínio público).

HYDRAULIC ENGINEERING

Dealing with the Practical Problems of the Operating and the Consulting Engineer

Taking the Temperature and Feeling the Pulse of the Test Dam on Stevenson Creek

By R. W. CARLSON

UNTIL recent years, arch dams have been designed in a very elementary way. The concrete has been assumed to carry loads without being deflected or strained and the arch has been treated as a portion of a rigid cylinder. The method for calculating the thickness of an arch section for assigned conditions has been too simple to be fascinating.

Increasing knowledge about concrete and increasing investments in arch dams has brought a flood of refinements in design. All of these refinements have been required in recognition of the well-known fact that concrete deforms. Perhaps the first of these has been to take account of the effect of temperature changes on the length and shape of the concrete arch. The second has been to include the effect of shortening and bending of the concrete arch under the water load. Next has been to compute the load carried by the vertical beam sections and reduce the load to be carried by the horizontal arch sections by this amount. Other refinements have been the analysis of the effect of lateral expansion due to load, the effect of shear, the effect of shrinkage, the effect of moisture absorption, and other important but very uncertain conditions.

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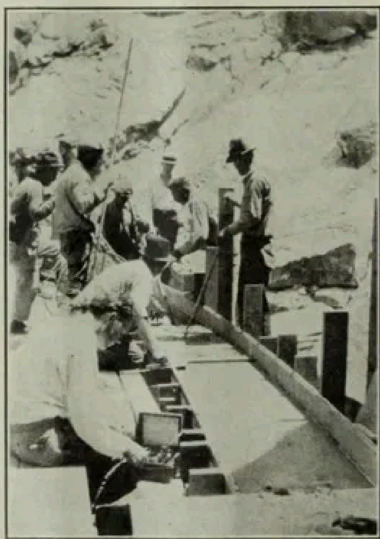
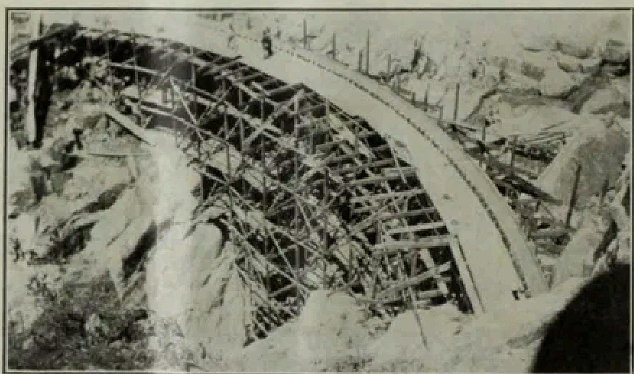
Realizing the certain gain in knowledge and economy which will accrue, the Engineering Foundation is sponsoring a full-sized test-to-destruction of a concrete arch dam. The site is located in the steep canyon of Stevenson Creek in the Sierra Nevada Mountains sixty miles east of Fresno, California, where the storage of water will be small and no damage can result from the ultimate failure.



ABOVE: *Author reading a telemeter, one of the many instruments used in the Engineering Foundation Dam.* BELOW: *The completed dam before the forms were removed.*



The dam has been completed to a height of sixty feet and will be tested extensively before being built higher. It is an unreinforced single arch of 140 foot crest length, 100 feet radius, seven and one-half foot thickness at the base, two foot thickness at the thirty foot level, with no change in thickness from that level to the crest. The abutments make angles of forty-five degrees with the horizontal on either side of the canyon, and the central portion of the foundation is a vertical arc of twenty-five foot radius. The concrete is uniform throughout and numerous tests of samples indicate that it is capable of supporting more than two thousand pounds per square inch.

METERS AND GAUGES

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Figure 4 / Figura 4 — Modern Irrigation, July 1926, p. 22 (Carlson article, first page) change-of-radius meter. The movements of central portions of the dam upstream or downstream are measured from the sides of the canyon by means of surveyors' theodolites with telescopes of high power. Measurements are to be made to detect tilting of the foundation at five stations by placing an especially designed level bar on heavy I-beams anchored and grouted in the rock. Separation of the dam from the foundation at some points has already been found by measuring gauge lines spanning from the foundation to the dam. Internal distortions and temperatures are measured by 140 carbon resistor strain gauges (known as telemeters) buried in the concrete.

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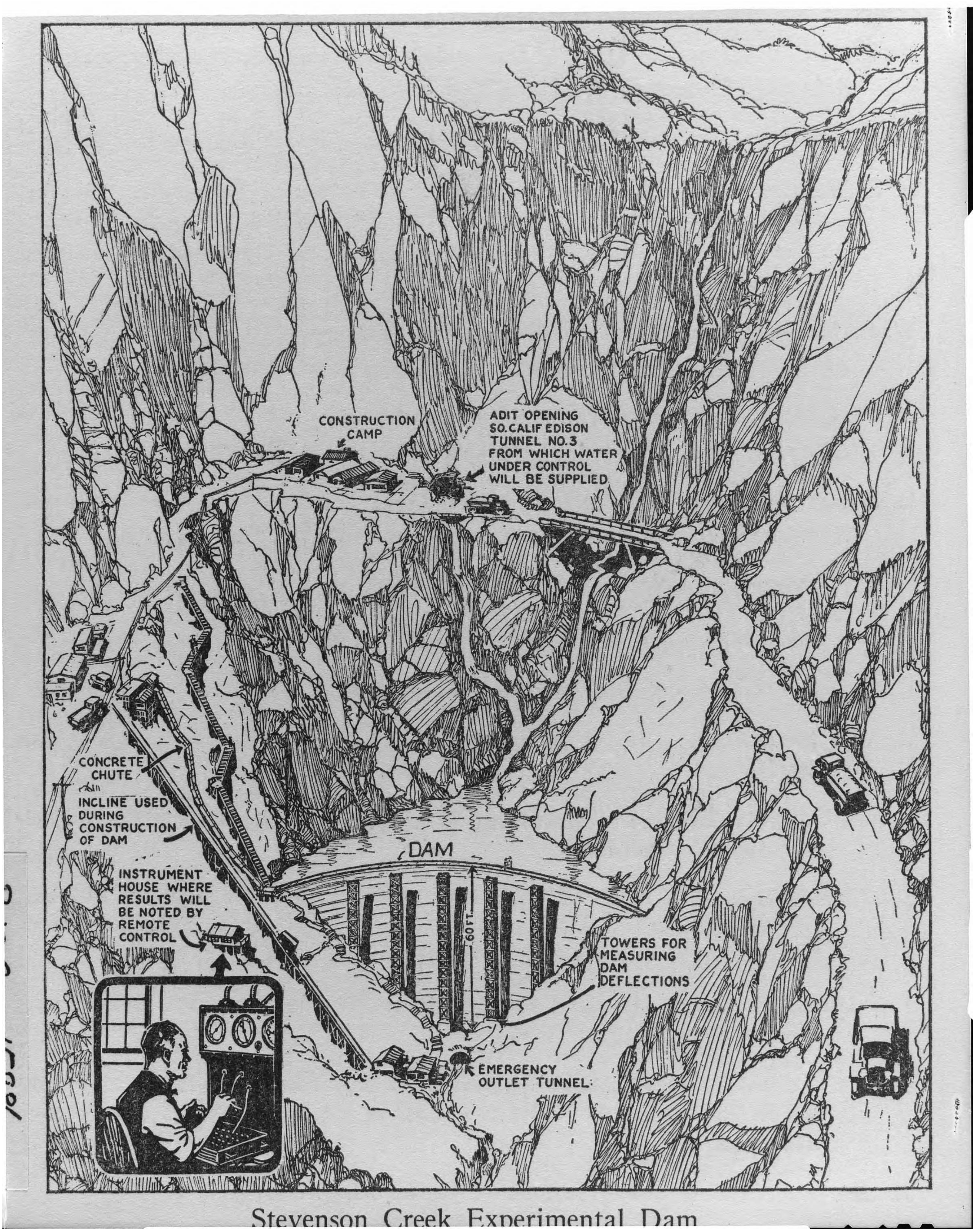
New Cement Manager

J. E. Jellick, for the last three years district engineer in charge of the Los Angeles office of the Portland Cement Association, has been appointed manager of all the Pacific coast offices. He will make his headquarters at 785 Market Street, San Francisco.

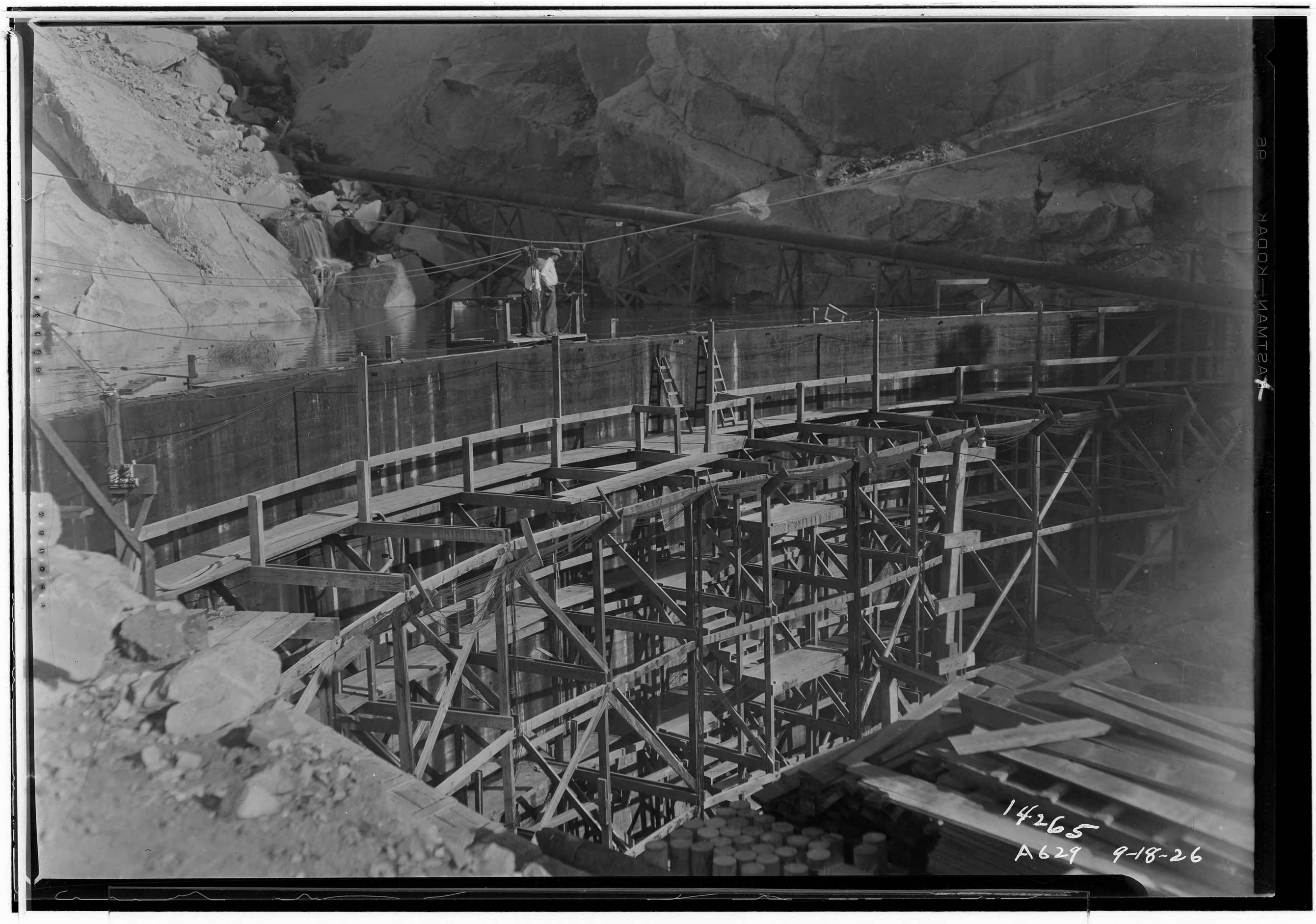
Figure 5 / Figura 5 — Modern Irrigation, July 1926, p. 24 (Carlson article, continuation)

8. Historical photographs / Fotografias históricas



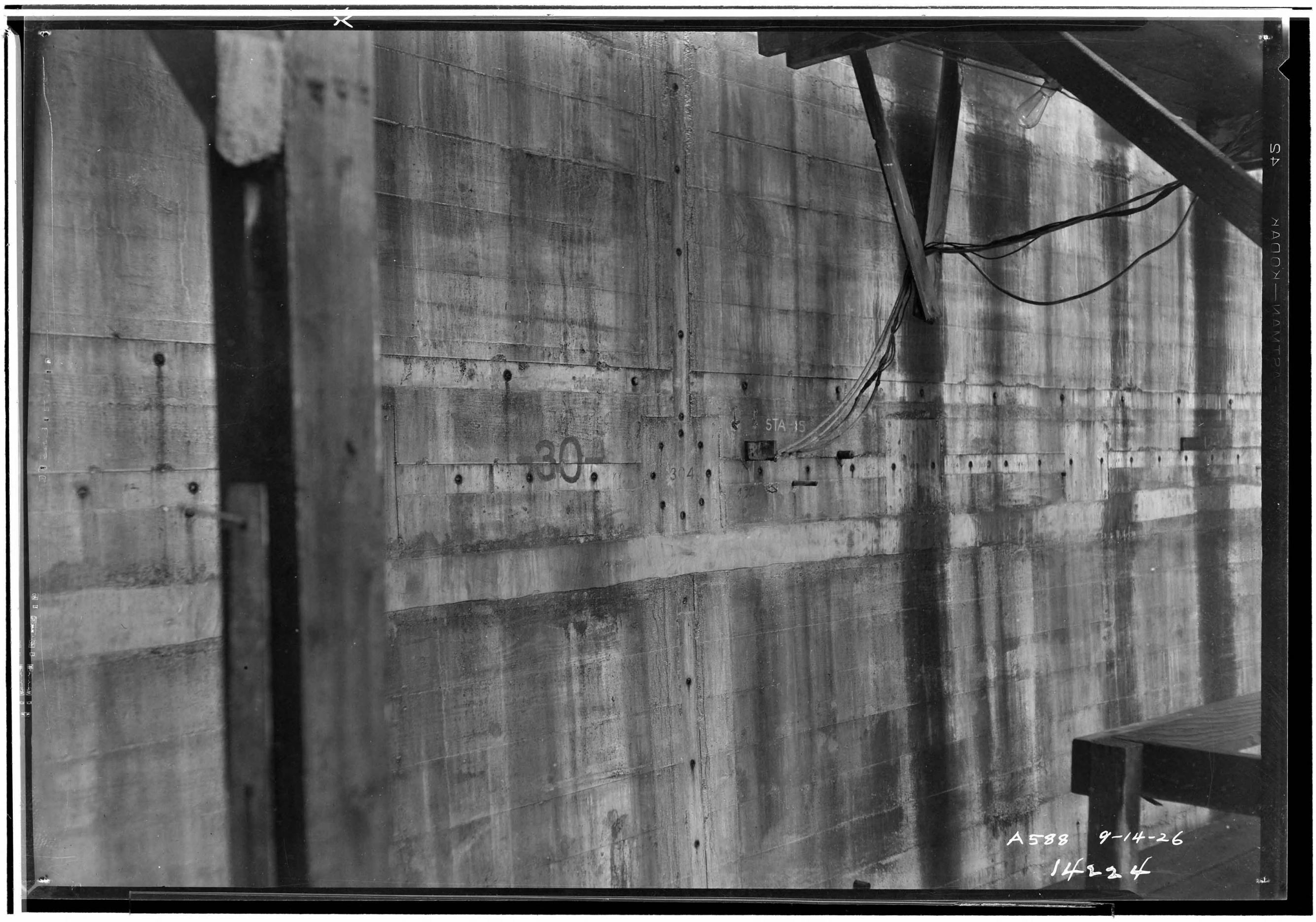
Stevenson Creek Test Dam — site overview / schematic

Stevenson Creek Test Dam — view 1



Stevenson Creek Test Dam — view 2

Stevenson Creek Test Dam — view 3



Instrumentation wires on the dam face, 14 Sep 1926


14289
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R. W. Carlson at Stevenson Creek, 1926

Sources / Fontes (Calisphere / Huntington Library; facsimile *Modern Irrigation* 1926; telemeter after Glisic 2022 / McCollum & Peters 1924): see `credits.txt` in the article folder.

9. Full report / Relatório completo

The complete Engineering Foundation report on the Stevenson Creek Test Dam (facsimile of the scanned pages) is available as a free download in the IRC Library. Scan the QR code or open the link below.

O relatório completo da Engineering Foundation sobre a Barragem de Ensaio do Stevenson Creek (fac-símile das páginas digitalizadas) está disponível para download livre na Biblioteca IRC. Escaneie o QR Code ou abra o link abaixo.

QR Code — relatório completo / complete report

https://institutoroycarlson.org/biblioteca/files/public/stevenson-creek-test-dam.pdf