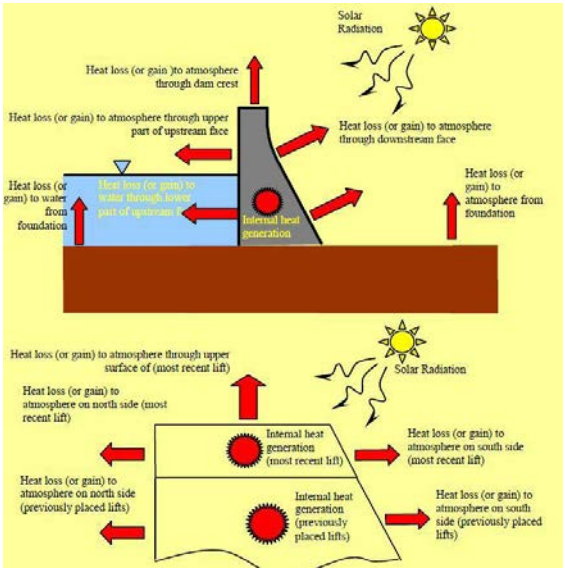
Dam Design Consulting Services

U.S. Army Corps of Engineers

Puerto Rico

MMI Engineering provided design consulting services for thermally induced crack control of the Portuguese Dam in Ponce, Puerto Rico, on behalf of the Jacksonville District Army Corps of Engineers. The Portuguese Dam, authorised by the Congress under the Flood Control Act of December 30, 1970, is the first single curvature thick arch dam constructed using Roller Compacted Concrete (RCC) by the Corps in the U.S. and the Caribbean.

Located in an area of high seismic activity, the dam design requires both gravity and arch action to carry seismic loads. Therefore, thermally induced cracking of the dam was a major concern. MMI was selected by the Corps to perform a comprehensive Nonlinear Incremental Thermal Stress-strain Analysis (NISA) of the dam to assess the magnitude of thermally induced strain and the potential for excessive cracking.



Hydration of concrete is an exothermic reaction and results in significant heat generation. For mass concrete structures, depending upon their size, it can take several years (10 years in case of the Portuguese dam) for the structure to reach a stable temperature distribution that is in equilibrium with ambient conditions. The volumetric change due to heating, together with the subsequent cooling / shrinkage of concrete, induces strains, which when resisted by internal restraints (such as hardened concrete) or external restraints, can cause cracks if they exceed the structure's tensile strain capacity.

MMI performed a combination of 2D and 3D analyses using NISA to predict the extent and location of cracking, to provide design recommendations related to the initial placement temperature, and to recommend the optimum location of contraction joints to the Corps. MMI's analysis considered several time dependent variables, including adiabatic temperature rise, initial concrete placement temperature, solar radiation, heat loss through convection, time dependent variation of concrete, nonlinear material properties (creep, shrinkage, modulus of elasticity, and tensile and compressive strengths) and straining of concrete (due to thermal and gravity loads). MMI used ABAQUS in conjunction with a special concrete material model, to include the effects of creep, shrinkage and tensile cracking. The analysis procedure required that the finite element mesh change in time, to model the incremental construction process and changes in the boundary conditions and loads. MMI evaluated optimum design considerations through parametric studies, such as day/night or winter/summer placement of concrete, or pre-cooling of aggregate.

Control of cracking in a dam is important for many reasons, including structural integrity, leak prevention, visual appearance and public confidence. At the design stage, the designer of the RCC dam faced two fundamental choices: to incorporate a grouting system within the dam to seal cracks after the dam had reached a steady state condition, or to select a combination of design parameters, for example pre-cooling of the concrete mix or post-cooling of the dam through embedded cooling coils, so that cracks would not open). Each choice had economic implications that needed to be carefully considered. MMI's analyses enabled the Corps to make such informed design decisions.

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