Risk Assessment and Functional Check of Static or Quasi-static components at hydro plants: an application to gated weirs and outlet works

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Intro

Gated spillways/weirs and gates at outlet works have a fundamental role in guaranteeing the safety of the operation of dams or weirs. These equipment are commonly designed to last and operate for decades, but periodic checks related to structural and functional stability must be performed.

For these components, in fact, in addition to the actual structural static checks, the checks of the whole system, that is, of the set of components that guarantee their functionality, are also crucial and of interest. These components do not directly relate to and only to the structure itself, (leaf, beams, etc.). In fact, it is understood that a gate structurally perfect, but that it cannot be operated due to the poor maintenance or due to the actions on other components as a whole, can represent a critical element for the safe operation of the weir/dam in which it is located.

This issue is particularly sensitive in many countries with a long history in hydropower where dams and gated weirs are sometimes century old (e.g. the average age of hydropower dams and weirs in Italy is more than 70 years and the relevant gates as well).

In the paper a method, based on the Failure Mode Event Analysis and the set-up of Safety Functions of the components which guarantee the functionality of the gates is fully described.

This analysis can be included in the assessments relating to the Damage Limit State of the Seismic Analysis of the gate and it is based on the analysis of the failure modes of the components that guarantee the functionality of the gate and on the correlation with the effects of the seismic actions.

The final goal is the verification of the functionality of the gate with a YES/NO, not as a result of a single final and decisive test, but as an outcome of a series of checks which from time to time - depending on the characteristics of the single gate – are met along the way.

Therefore, a flow diagram is proposed which, starting from the retention structure - the gate shield, which in any case represents the basic element of the verification - will gradually move away both physically and functionally, meeting various elements for which the effects on the operation of the gate will be evaluated by establishing verification criteria, functionality evaluation parameters, calculation methods for verification - where appropriate and where pertinent and applicable - and acceptability thresholds.

The functional check is divided into two parts:

• determination of the safety function and of the equipment indispensable for its performance

• functional check of the single piece of equipment identified in the previous point

These check has as a prerequisite the positive outcome of the static and seismic checks of the structure itself: it is therefore assumed that the gate is still able to move following the earthquake.

The hypotheses adopted for the determination of probable equipment failures result from experience and good practice; however, in some cases it is possible that these hypotheses need to be reviewed jointly with the technicians in charge of the plant who know the preparation of the operators or the availability of equipment in the plant. For example, the acceptability of repair times in the event of a breakdown depends on the training of on-call personnel and the availability of spare parts on site.

A case study is used to describe the application to a real situation: this is deemed as the simplest way to show how the method works.

The method is applied to a spillway gate located in the central part of a dam where a 12.00 x 5.75 m sector self-leveling gate with automatic hydraulic control is installed. The gate is made up of a lattice beam steel structure. The sealing diaphragm is obtained by means of a cylindrical coating (10.00 m radius) of 7 mm thick sheet steel applied to longitudinal metal beams. These are connected to two steel pins arranged on bronze bearings with a spherical seat joined to the piles by means of steel tie rods. The truss arms extend downstream of the pins for a length of 4.00 m and carry the counterweight for balancing the gate at the ends, made up of reinforced concrete caissons with a total weight of 288 kN. The gate can be lifted automatically by opening the water inlet gate located in correspondence with two rectangular wells obtained in the side piers, within which floating caissons are housed. However, it is possible to move the gate regardless of the upstream water level, by means of a winch operated by an electric motor or by hand with a crank.

1. Functional check - Step 1

1.1 - Determination of the safety function and of the equipment indispensable for its performance

The functional analysis is carried out following a rather simple flow diagram.

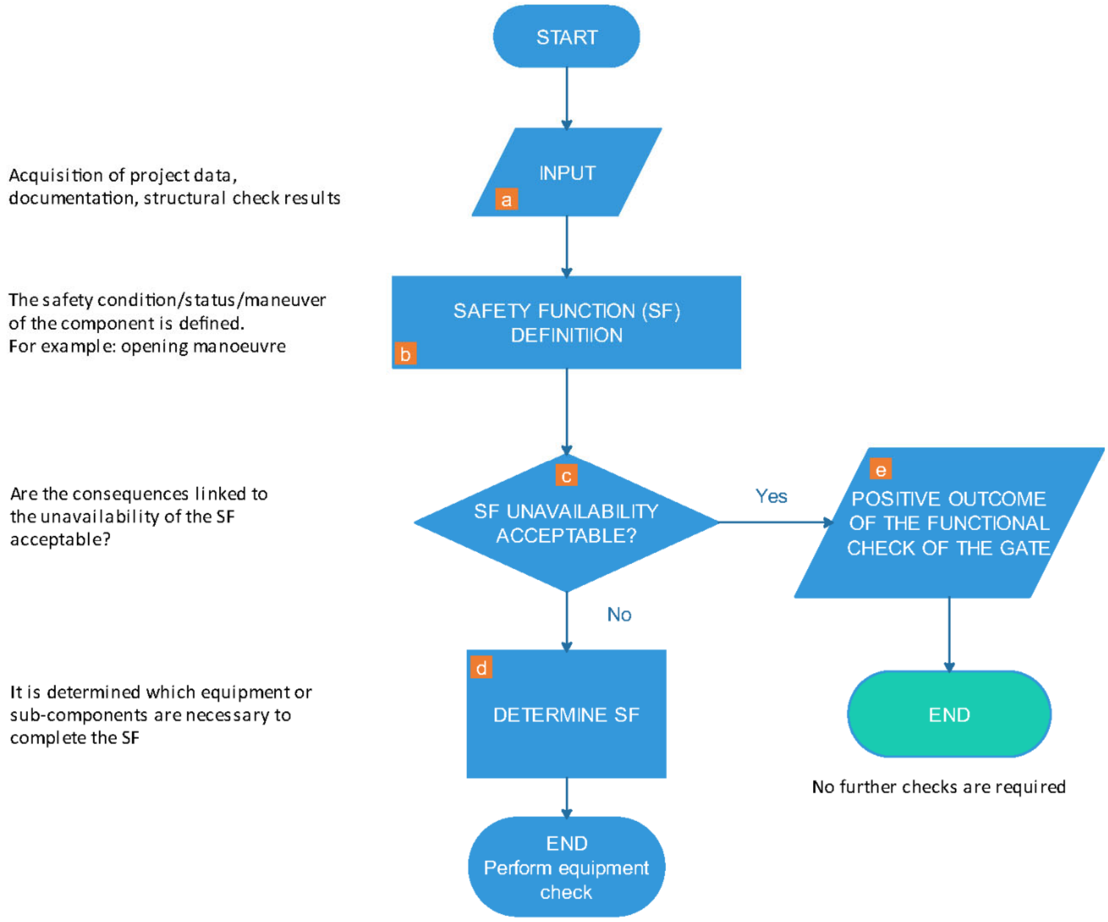


Fig. 1. Flow diagram showing the determination of the Safety Function

1.2 – How to carry out the safety function - Chain of the components to get the Safety Function

The gate has two opening modes:

1. Opening via lifting floats
2. Opening with chain winch

Therefore, the second of the SFs, i.e. the lack of uncontrolled release of water in the Collapse Limit State, is always satisfied because the seismic verification of the retaining structure is.

The safety function chain will branch out to account for the double use possibility.

It should be noted that lifting with floats is not possible at all reservoir levels unlike lifting with a chain winch.

In the following charts the set of components that guarantee the Safety Function and the general schemes are shown:

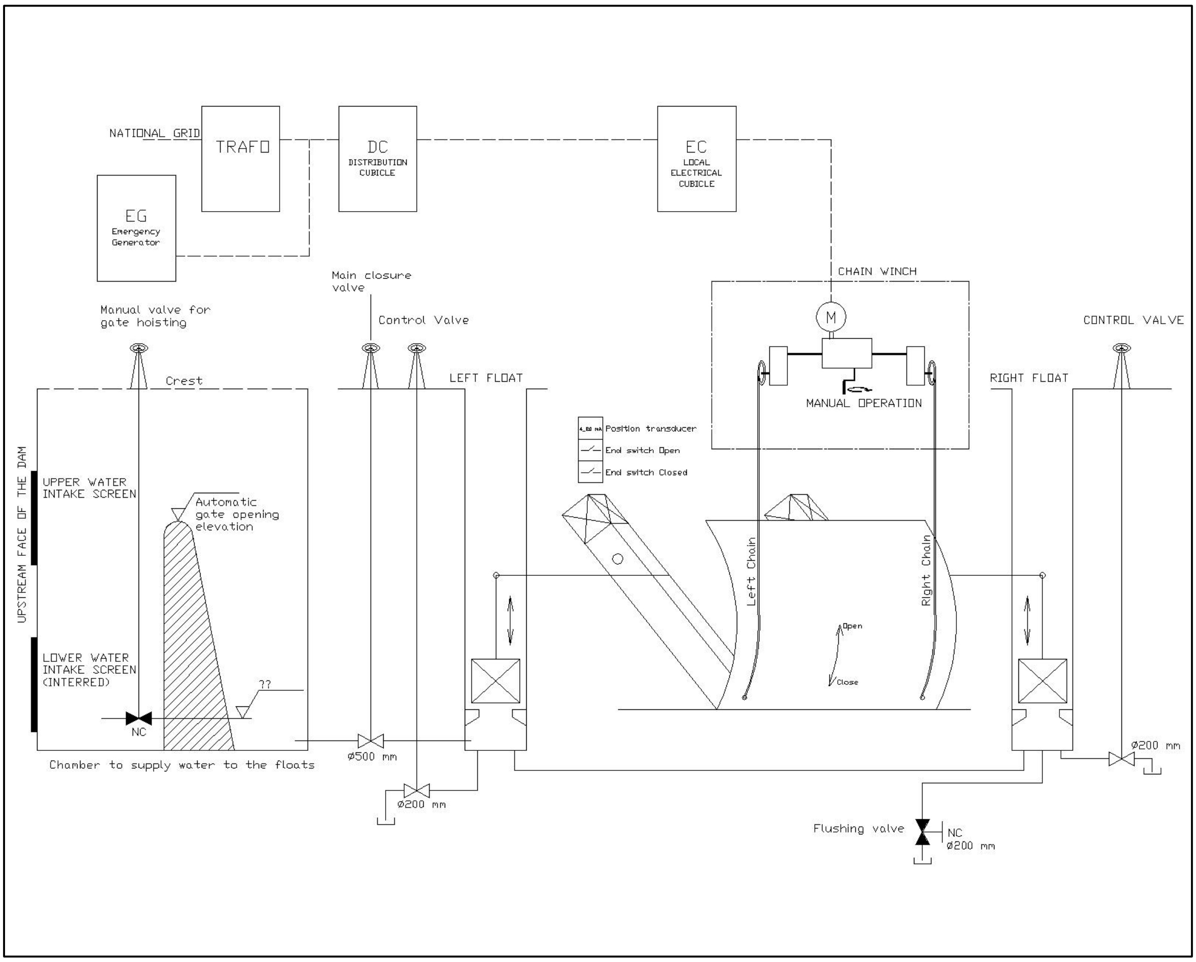


Fig. 2. Functional scheme of the gate

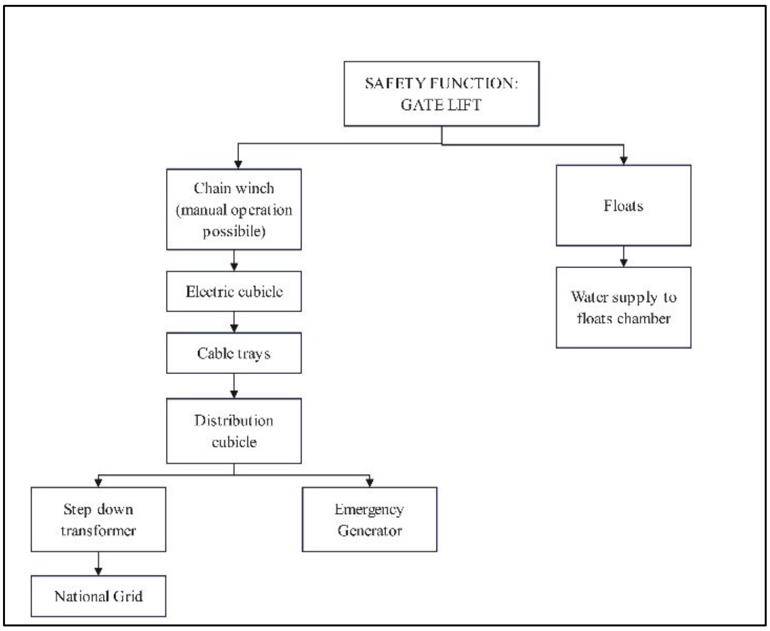
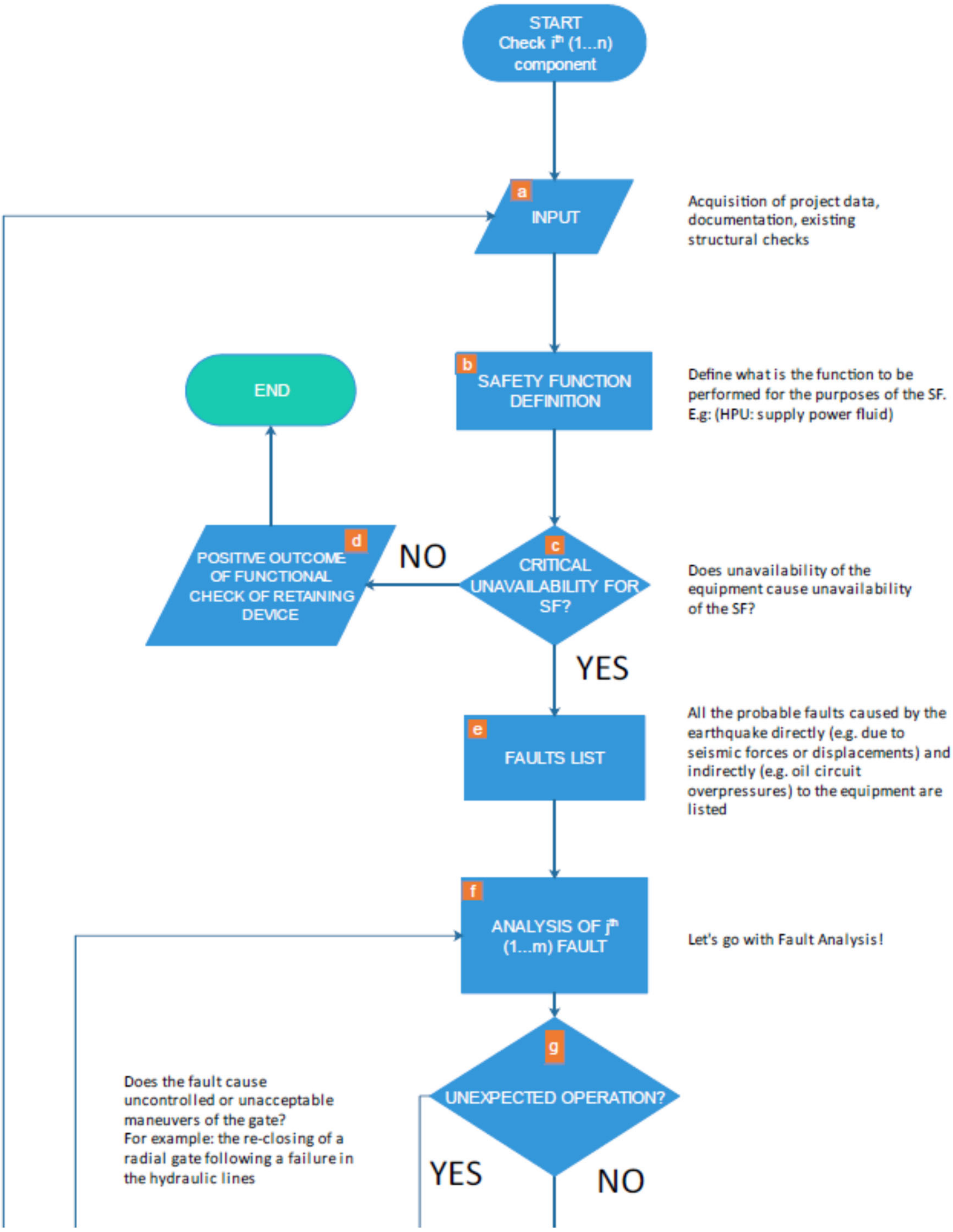


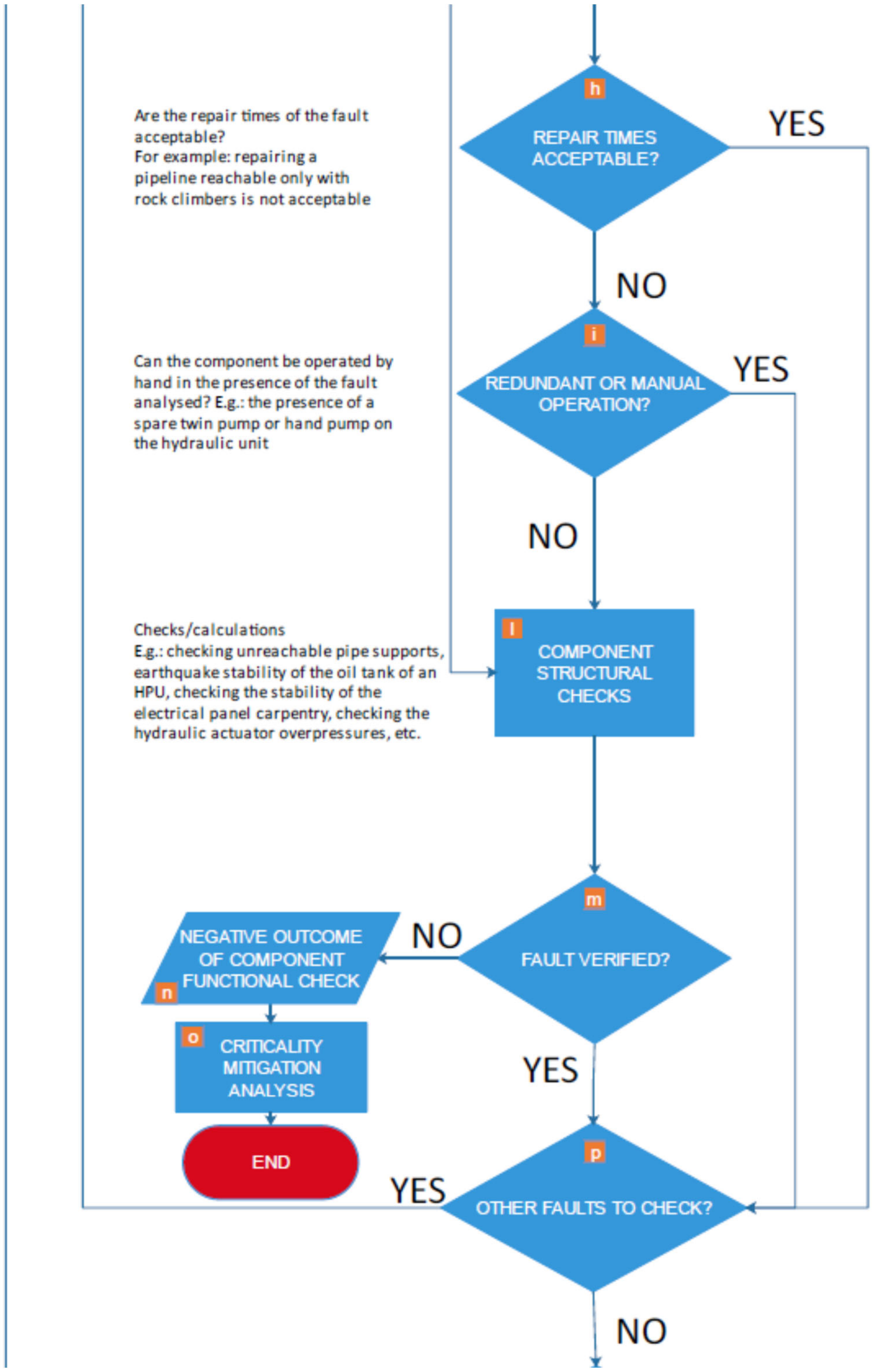
Fig. 3. Chain of the Safety Function

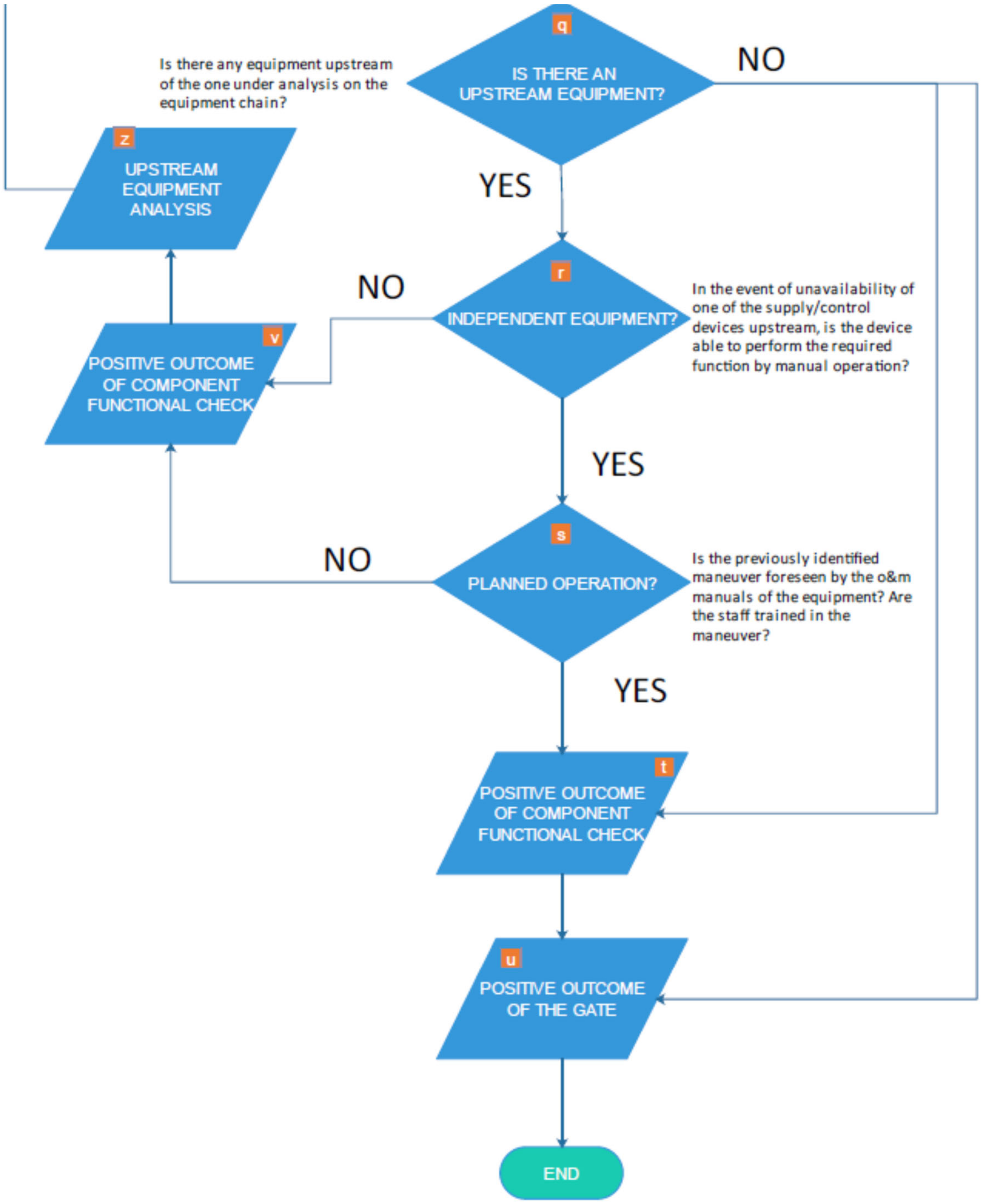
2. Functional check - Step 2 – Check of the single component

2.1 – General procedure

For each relevant component of the chain of the Safety Function of Fig. 3 the functional check is carried out according to the a flow diagram rather complex. In the next pages the procedure is applied to components of the gate at hand.




Are the repair times of the fault acceptable?
For example: repairing a pipeline reachable only with rock climbers is not acceptable
h
REPAIR TIMES ACCEPTABLE?
YES
NO
Can the component be operated by hand in the presence of the fault analysed? E.g.: the presence of a spare twin pump or hand pump on the hydraulic unit
i
REDUNDANT OR MANUAL OPERATION?
YES
NO
Checks/calculations
E.g.: checking unreachable pipe supports, earthquake stability of the oil tank of an HPU, checking the stability of the electrical panel carpentry, checking the hydraulic actuator overpressures, etc.
l
COMPONENT STRUCTURAL CHECKS
m
FAULT VERIFIED?
NO
n
NEGATIVE OUTCOME OF COMPONENT FUNCTIONAL CHECK
o
CRITICALITY MITIGATION ANALYSIS
END
YES
p
OTHER FAULTS TO CHECK?
YES
NO



2.2 – Application to a component: the gate hoist

a	**Input:** The chain hoist for lifting the gate consists of two chains connected at one end to the lower part of the gate leaf and at the other to two reducers placed on the sides of the gate on the walkway at the top of the dam. The reducers receive motion from a kinematics which connects them to the central motor-driven reducer equipped with a crank for manual operation. Conservation status: the state of conservation of the chain immersed in water and of the chain connection on the gate is not known. The equipment placed on the walkway appears to be in good condition, but there is no news regarding the latest overhaul.

b	**Safety Function Definition:** Transmit motion to the gate to allow it to be lifted
c	**Critical unavailability for the SF?** Yes
d	POSITIVE OUTCOME OF FUNCTIONAL CHECK OF RETAINING DEVICE
e	**FAULT LISTS** 1. Break of the chain or of the chain-gate link – **Go to f1** 2. Failure of gear reducers due to overstress due to earthquake – **Go to f2**

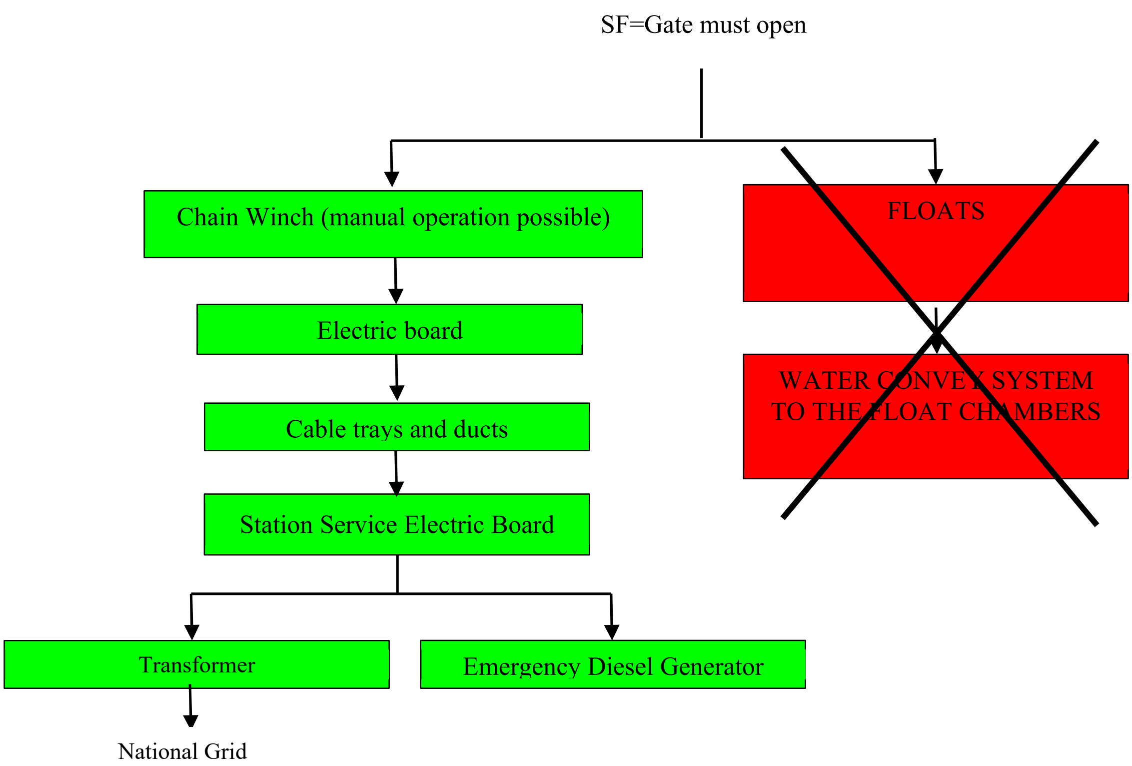
f1	**ANALYSIS OF FAULT #1**
As the chain is under tension only when the winch is activated and that the simultaneity of the activation with the earthquake is excluded, the breaking of the chain, but in particular of its attachment to the diaphragm of the gate due to the greater stresses induced by the earthquake it is also to be excluded.	
g1	**UNEXPECTED OPERATIONS?**
Yes	
h1	repair times acceptable?
i1	redundant or manual operation?
l1	**COMPONENT STRUCTURAL CHECKS**
The absence of tension in the chain during the earthquake means that no greater tensions are induced than under normal operating conditions. Since the periodic activations envisaged by the operation procedures are regular, the check is positive	
m1	**FAULT VERIFIED?**
Yes	
n1	NEGATIVE OUTCOME OF FUNCTIONAL CHECK
o1	CRITICALITY MITIGATION ANALYSIS
p1	**OTHER FAULTS TO CHECK?**
Yes, go to f2	

f2	**ANALYSIS OF FAULT #2**
The most common damage on this type of appliance concerns the teeth of the chain return sprockets, but the gears of the reducers could also be damaged.	
g2	**UNEXPECTED OPERATIONS?**
Yes	
h2	repair times acceptable?
i2	redundant or manual operation?
l2	**COMPONENT STRUCTURAL CHECKS**
The absence of motion during the earthquake means that no greater stresses are induced than under normal operating conditions. Since the periodic activations envisaged by the operation procedures are regular, the check is positive	
m2	**FAULT VERIFIED?**
Yes	
n2	NEGATIVE OUTCOME OF FUNCTIONAL CHECK
o2	CRITICALITY MITIGATION ANALYSIS
p2	**OTHER FAULTS TO CHECK?**
No, go to q	

q	**IS THERE AN UPSTREAM EQUIPMENT?**
Yes, the control panel of the winch	

r	**Is the component independent in case of fault of the upstream equipment?**
Yes, the winch can be manually operated	
s	**Is the action described in operation manual and the personnel trained for the action?**
Manual operation is covered by procedures and the personnel is trained. The action is periodically done as for available check reports	
v	**POSITIVE OUTCOME OF FUNCTIONAL CHECK OF THE COMPONENT**
The Safety Function is guaranteed under Limit State of Damage seismic actions. The loss of the Safety Function under Limit State of Collapse seismic actions doesn't entail uncontrolled release of water downstream of the dam	
z	**Next component analysis**
Control panel of the winch	

2.3 – Final outcome of the analysis
The repeated application of the procedure analysis to each component has as final outcome a flow diagram similar to the next one:



As you can see, even though not all the systems to get the Safety Function are available, thanks to the analysis carried out on each component, it's possible to conclude that the Safety Function is guaranteed.
The analysis gives also additional information about the functionality of the components in getting the Safety Function, focusing on the opportunity of actions to restore the complete availability of all the components.

3. Conclusions

Gated spillways/weirs and gates at outlet works have a fundamental role in guaranteeing the safety of the operation of dams or weirs. These equipment are commonly designed to last and operate for decades, but periodic checks related to structural and functional stability must be performed.

In the paper a method, based on the Failure Mode Event Analysis and the set-up of Safety Functions of the components which guarantee the functionality of the gates has been fully described.

This analysis is based on the analysis of the failure modes of the components that guarantee the functionality of the gate and on the correlation with the effects of the seismic actions.

The final goal is the verification of the functionality of the gate with a YES/NO, not as a result of a single final and decisive test, but as an outcome of a series of checks which from time to time - depending on the characteristics of the single gate – are met along the way.
The application of this method somehow forces the operators to go into the details of the functioning of the individual components.
Like any analysis, it must be fed with detailed information on the state of conservation, efficiency and functioning of the components: therefore the implementation of the model is sometimes an occasion, for existing plants, to update information on components of sporadic use, but essential for infrastructure security.

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