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MULTILAYER WALL SYSTEM FOR PROTECTION OF NUCLEAR FACILITIES AGAINST AIRPLANE CRASH

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ABSTRACT

The load case airplane crash (APC) for design of the first and second generation nuclear power plants was taken into account by some regulatory commisions like Germany according to DIN 25449 (2008) and Switzerland as impact of a military aircraft, but neglected by other countries as for example by Japan and South Korea. Since 09/11/2001 more and more regulatory commissions require that the load case impact of a commercial aircraft shall be considered within the design and approval process. There is no unique requirement regarding the commercial aircraft type, which has to be taken into account. Some regulatory commissions prescribe the consideration of an A320, while other require a B747 or even an A380.

Nuclear facilities that could sustain the impact of an A320 usually need an external wall thickness of 1,80 m. The increase of the requirement to an aircraft type A380 leads to problems regarding the design and verification of the resistance against APC.

Due to these reasons, Max Aicher GmbH & Co. KG (2021) developed a multilayer wall system (MLWS), which has significant advantages in comparison to the massive wall (MW) for the load case APC on one side and has compatible properties with a MW for the load case design basis earthquake (DBE) on the other side. For the load case DBE the MLWS shows almost identical response as the MW. The dynamic response of the MLWS for the load case APC is characterized with significantly lower strain at the inner side of the impacted structure in comparison to the dynamic response of a MW, thus reducing the requirements for design and qualification of components.

INTRODUCTION

The design process of nuclear facilities requires that all possible scenarios of accidents shall be considered and that also in case of an extreme external impact a safe shutdown of the facility without release of radiation shall be performed. For the first two generations of nuclear power plants it was required by some regulatory commissions that the resistance of the structure and components against the impact of military aircraft shall be verified (DIN 25449, 2008).

Since the terrorist attack of September, 11/2001, more and more regulatory commissions require that the load case impact of a commercial aircraft shall be part of the design process. Opposite to the load case impact of military aircraft, there is no standardized load function and no prescribed design procedure, defined in regulations for the load case impact of a commercial aircraft. The load function parameters for the impact of a commercial aircraft is considered as confidential and not published by regulatory commissions. For each new build nuclear facility the regulatory commission in charge prescribes a specific commercial aircraft impact load function and the required APC resistance verification procedure. The requirements for nuclear facilities, currently being built in Europe regarding the load case APC are based on an A320. In calls for new bids, the resistance again an APC of B747 or even A380 is required.

According to RCC-CW (afcen, 2018) and US NRC (2011) the resistance of the building structure for the load case APC shall be verified by proving that following strain limits are not exceeded:

ε_s^{pl} = 5 % for the concrete steel

ε_{cu} = -0,5 % for the concrete

The verification of the resistance of a nuclear facility against the impact of a commercial aircraft A320 with “State of the Art” procedures led so far to a monolithic wall with a thickness of 1,80 m. The increase of the requirements to a B747 or A380 would lead to wall thicknesses, whose implementation would be problematic due to technological and economic reasons.

Another significant issue within the dynamic analyses for the load case APC are the induced high frequency vibrations, which do exceed the DBE design spectra in the high frequency range above 20 Hz (Vlaski, et al., 2013). Massive concrete walls do not provide any significant capacity for absorption of APC induced high frequency vibrations but do transfer them into the inner structure, which results in huge requirements for the design and qualification of components.

These issues are the basis for the development of a multilayer wall system (MLWS) by Max Aicher Engineering. The MLWS behaves for the load case DBE similar to the dynamic response of a MW, while for the load case APC a significantly more favorable response is established.

The deformation capacity of the building structures is evaluated in the current paper with the Riera Method (Riera, 1968, 1980, 1982) according to the recommendations of US NRC (2011) and NEI (2011). The calculations are performed with LS-DYNA (2018), using the Winfrith concrete model described by L. Schwer (2011).

MASSIVE WALL (MW) EXPOSED TO COMMERCIAL AIRCRAFT IMPACT

A massive wall with dimensions 40 m x 20 m x 1,80 m, shown in Figure 1, fixed at the boundaries and exposed to the impact of an Airbus A320 is considered as reference.

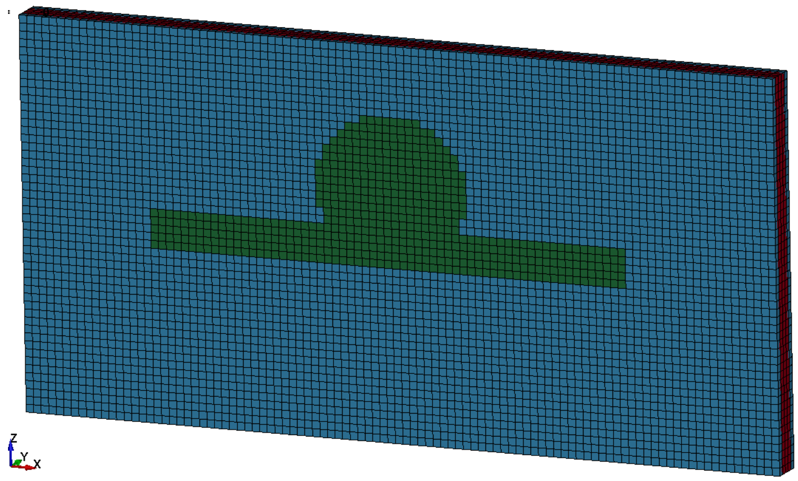
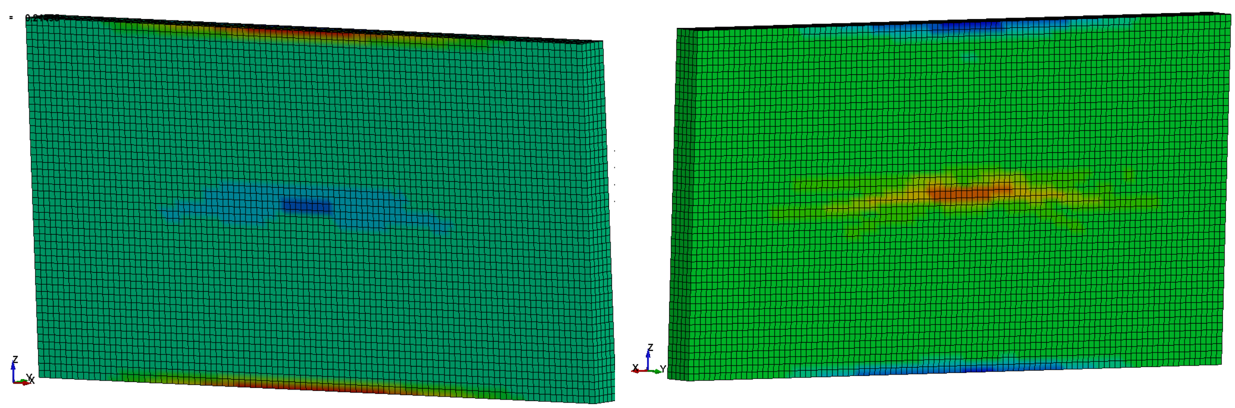


Figure 1: Reference Massive Wall (MW) 40 m x 20 m x 1,8 m

The maximum compression and tension strain of the reference MW, exposed to the impact of an Airbus A320 is depicted in Figure 2.



MW max. Compression Strain on Impact Side 1,81 % MW max. Tension Strain on Inner Side 2,99 %

Figure 2: Maximum compression and tension strain of MV Wall

Although the maximum tension of the reinforcement at the MV inner side of 2,99 % is lower than the tension strain limit of 5 % according to RCC-CW (2018), there is no capacity to sustain increased requirement like the impact of an Airbus A380, whose impact energy is much higher than the one of an A320.

MULTILAYER WALL SYSTEM (MLWS) EXPOSED TO COMMERCIAL AIRCRAFT IMPACT

As an alternative to the massive wall, a multilayer wall system (MLWS), depicted in Figure 3, is introduced.

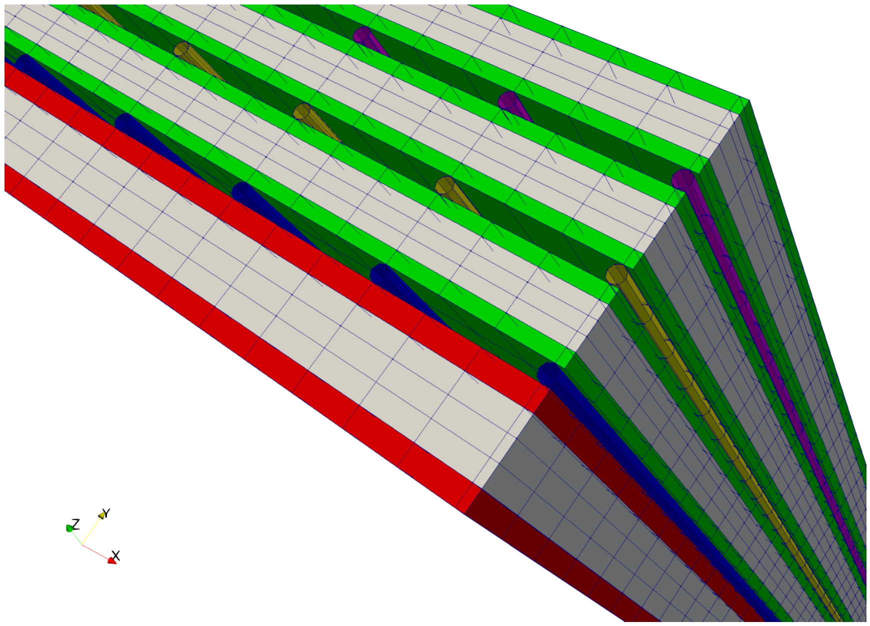


Figure 3: Multilayer Wall System (MLWS)

The MLWS consists of 4 reinforced concrete walls. The outer impacted wall is 60 cm thick, while the thickness of the other 3 walls is 40 cm each. The four walls are separated by free space in which steel pipes are mounted. The steel pipes are designed so that in case of DBE they do not deform nonlinear, but are capable to provide sufficient stiffness to the structure. For the load case APC high deformations lead to nonlinear deformations of the steel pipes. Due to the modular construction of MLWS it is possible to vary the number of reinforced walls and free space with steel pipes according to the requirements.

The dimensions of the MLWS reinforced concrete walls, of the steel pipes and the distance between the steel pipes are evaluated out of the condition that the dynamic response of the MLWS for the load case DBE shall be compatible with the dynamic response of the reference MW. The first dominant eigenvalue of the reference MW with fixed boundary conditions is at the frequency of 15,748 Hz with modal mass mobilization of 69,46 % in the direction vertical to the MW plane. With a parametric study and variation of the steel pipe distance and thickness, presented in Table 1, a compatible eigenfrequency of the first dominant eigenvalue of the MLWS at 15,613 Hz can be reached for pipe thickness of 10 mm and pipe distance of 0,50 m.

Table 1: Dominant MLWS eigenfrequencies as a function of pipe distance and pipe thickness

Pipe Dist. [m]	Pipe Thk. [mm]	Eigenval. 1 [Hz]	Pipe Thk. [mm]	Eigenval. 1 [Hz]	Pipe Thk. [m]	Eigenval. 1 [Hz]
40,0	10	3,639	5	3,637	2,5	3,633
20,0	10	4,429	5	4,367	2,5	4,256
8,0	10	7,856	5	7,171	2,5	6,269
4,0	10	10,513	5	9,438	2,5	8,066
2,0	10	12,832	5	11,695	2,5	10,117
1,0	10	14,524	5	13,600	2,5	12,158
0,5	10	15,613	5	14,983	2,5	13,893

Comparative calculations of the dynamic response due to the load case DBE, with excitation based on EUR hard soil spectrum of EUR (2016) scaled to a PGA of 0,4 g have been performed for MW and MLWS system. The dynamic response of both, MW and MLWS, are compatible as shown in Figure 4.

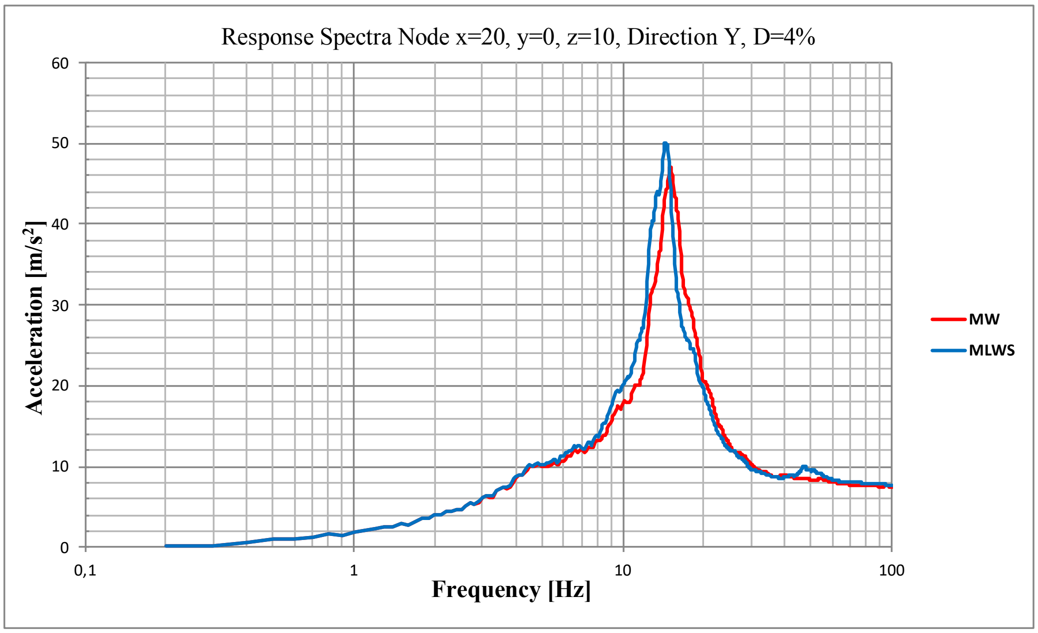
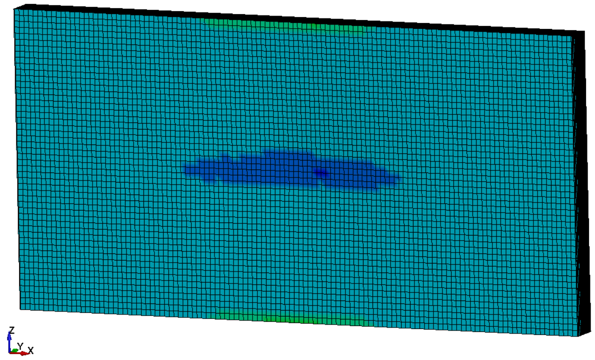
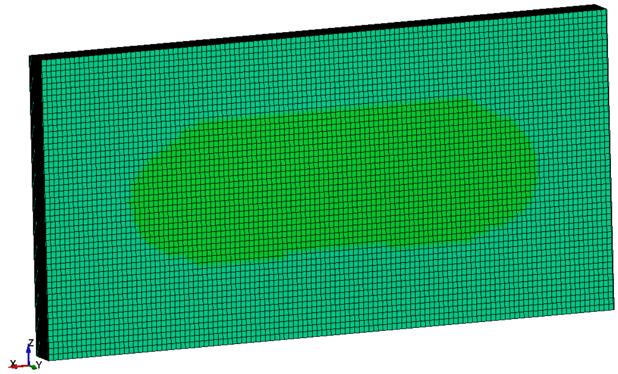


Figure 4: Response spectra MW and MLWS

In case of commercial APC, the deformations of the impacted wall are transferred through the pipes to the neighboring walls. The maximal compression strain at the impacted side of the MLWS is 2,10 %, while the maximum tension strain at the inner side of the MLWS is 0,25 %, as presented in Figure 5.





MLWS max. Compression Strain on Impacted Side 2,10 % MLWS max. Tension Strain on Inner Side 0,25 %

Figure 5: Maximal compression and tension strain of Multilayer Wall System (MLWS)

The deformation states of the MLWS due to APC of an Airbus A320 at selected times are depicted in Figure 6. At time of 0,175 sec. the deformation of the impacted wall is so huge that the first row of pipes starts with nonlinear deformation. At 0,235 sec. the nonlinear deformation of the first row of pipes is completed, the first two walls segments have established contact and the nonlinear deformation of the next row of pipes starts. After 0,285 sec. significant transfer of deformation to the inner wall segment starts.

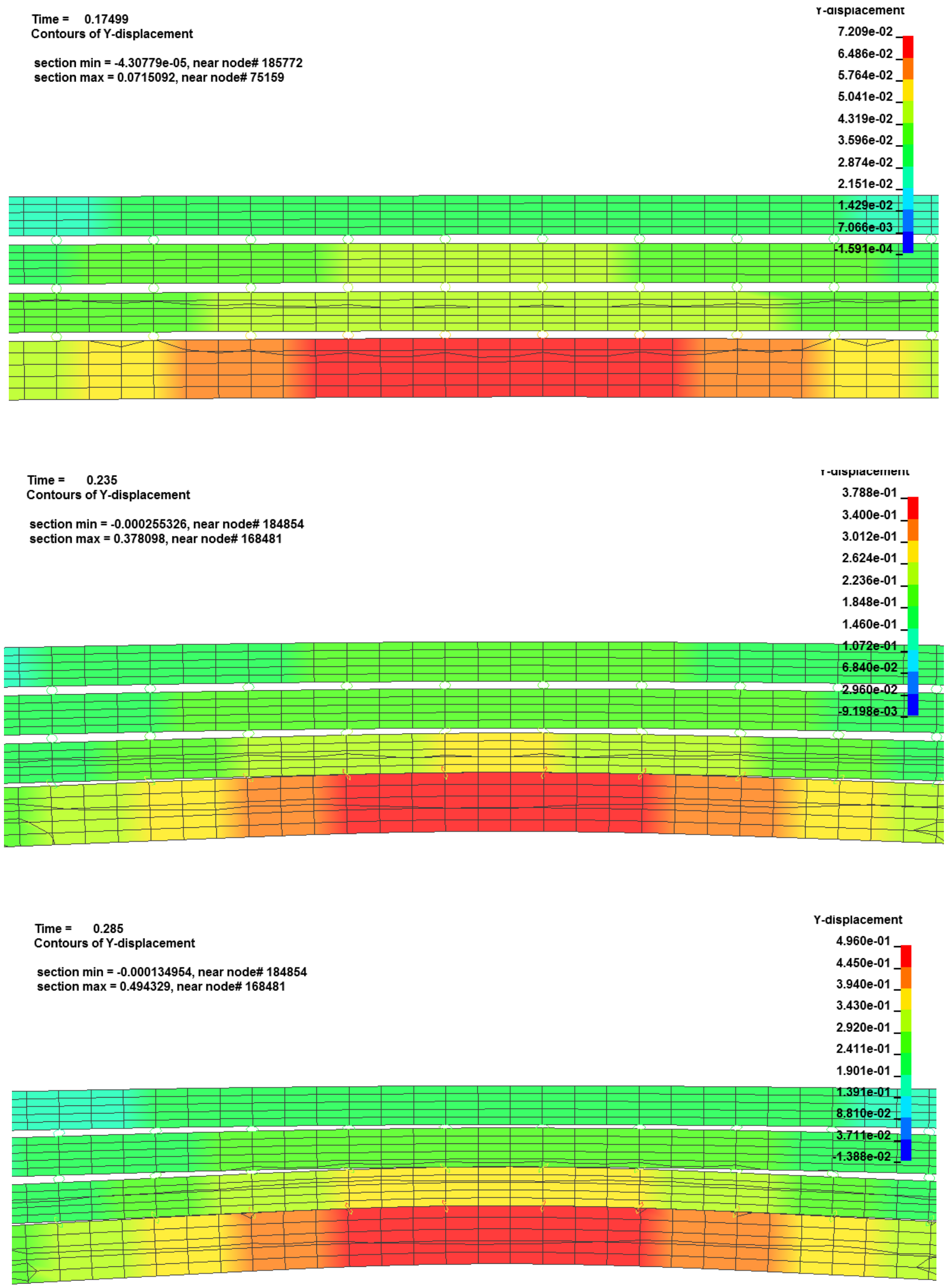


Figure 6: Deformation states of the Multilayer Wall System due to APC A320

COMPARISON OF THE DYNAMIC RESPONSE OF MW AND MLWS DUE TO THE LOAD CASE APC OF AN A320

The maximum tension and compression strains of the massive wall (MW) and the multilayer wall system (MLWS) developing over time of impact are presented in Figure 7.

The compression strain of the concrete at the impacted side does exceed the limits of -0,5 % prescribed by RCC-CW (afcen, 2018) both for MW and MLWS.

The tension strain at the inner side of the MLWS are just 0,25% and by a magnitude lower compared to the tension strain at the inner side of MW 2,99 %.

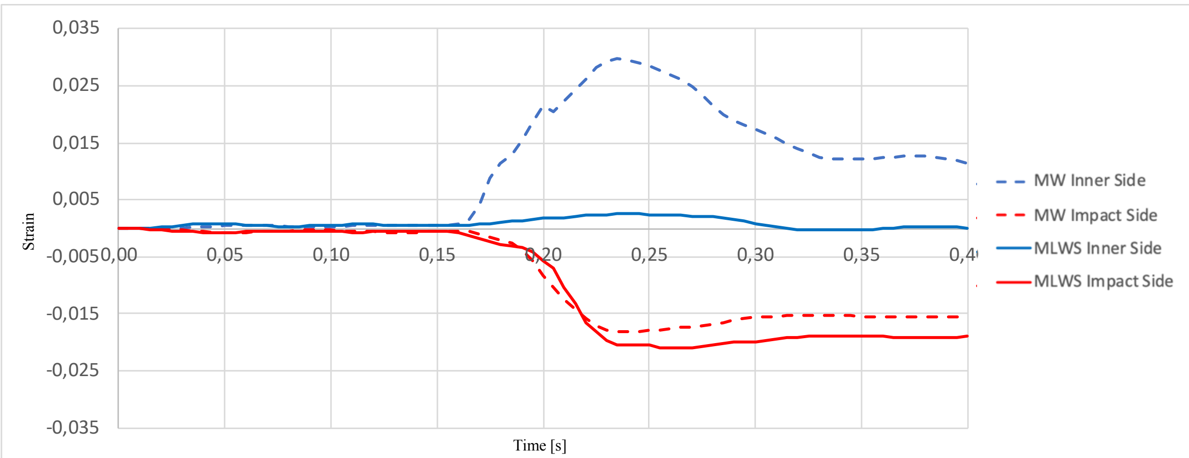


Figure 7: Maximum tension and compression strain of MW and MLWS

Out of the performed analyses it can be summarized:

- The compression strains at the impacted side are both for MW and MLWS higher than the limit of -0,5% according to RCC-CW (afcen, 2018). This exceedance will result for the MW in progressive failure, while for the MLWS just the first wall layer will fail
- The maximum tension strain at the MLWS inner side is distributed over a larger area, while for the MW localized concentration of high tension strain is evident
- The tension strain at the inner side is 2,99 % for the MW and 0,25 % for the MLWS. In case of MW, there is no available capacity to sustain increased demand of APC protection for larger commercial aircraft types than A320 as for example B747 or A380. Due to the modular construction of the MLWS, the number of concrete layers and steel pipes can be varied in order to control the desired reinforcement and concrete strains at the inner side of the impacted structure
- The MV transfers high frequency APC induced vibrations unfiltered into the building structure due to its own huge stiffness. On the other side in case of MLWS due to the nonlinear deformations of the steel pipes filtering of high frequency APC induced vibration occurs, significantly reducing the requirements for design and qualification of components

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