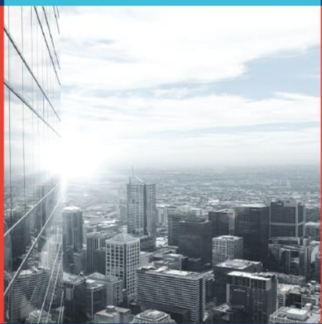

The Comparison between AS3600:2018 and ACI318M-14 for ULS Design of Reinforcement Concrete

STRUCTURE INSIGHT

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OVERVIEW

The ACI318M (US codes) and AS3600 (Australian codes) are very similar in basic approach. In the current documents, but, there is a number of significant differences.

Through this brief document, you can discover the differences between the two codes, understand their factors and design concepts.

In this document, comparison between ACI318M and AS3600 Code has 5 classified sections:

1. Strength Reduction Factor,

2. Concrete Rectangular Stress Block,

3. Strength Design in Shear,

4. PM Interaction,

5. Development Length.

In addition, the specific standards are based on the ACI318M-14 standards for US Codes, and AS3600:2018 for Australian codes.

1.1. Strength Reduction Factor

The strength reduction factors are the same concept in both codes and ACI 318M-14 has different strength reduction factors for spirals (0.75) and rectangular ties (0.65), in compression controlled sections, and has 0.90 for the largest value for tension controlled section, besides 0.85 for AS3600.

And, ACI 318 applies an additional reduction factor to concrete stresses for sections under uniform compression, as an allowance for unspecified load eccentricity, whereas AS 3600 specifies a minimum eccentricity.

You can check the strength reduction factor (Φ) between each standard in the table below.

Building Code	AS3600:2018	ACI318M-14
Axial Force Without Bending (Tension)	0.85 (for Class N reinforcement)	0.65 (& 0.75) to 0.90 Transition1: $0.65+0.25(\varepsilon_t-\varepsilon_{ty}$_/$(0.005-\varepsilon_{ty})$ Transition2: $0.75+0.15(\varepsilon_t-\varepsilon_{ty}$_/$(0.005-\varepsilon_{ty})$ Transition1: for ties(fitments) reinforcement Transition2: for spirals(helices) reinforcement
Axial Force Without Bending (Compression)	0.65	
Bending Without Axial Forces	0.65 to 0.85 Transition: $1.24-13k_{uo}/12$ (for Class N reinforcement)	
Shear and Torsion	0.75 (for Class N fitments are provided / (i) conditions)	0.75

1.2. Concrete Rectangular Stress Block

One of the most significant being in the definition of the concrete rectangular compressive stress block, for determination of the ultimate bending strength of beams.

The compressive stress block is an approximation to the actual stress distribution in a reinforced concrete member that takes advantage of the fact that the stress-strain curve of low to medium strength concrete has a wide plateau region where the maximum stress is maintained constant with increasing strain. In Section 8 of AS3600:3600 code, the factors were defined as;

$$\alpha_2 = 0.85 - 0.0015f'_c \qquad \alpha_2 \geq 0.67$$

$$\gamma = 0.97 - 0.0025f'_c \qquad \gamma \geq 0.67$$

Where α_2 is the factor on the compressive stress and γ is the factor on the depth of the stress block. This variable is similar to the formula of the Canadian concrete standard (CAN-A23.3-04), and the upper limit (0.85) for the γ factor has been removed compared to the formula of the existing Australian code (AS3600-2009). In ACI318M code, α_2 and γ factor of AS3600 code are the same concept as α_2 and β_1 factor respectively.

So, look at the comparison table below.

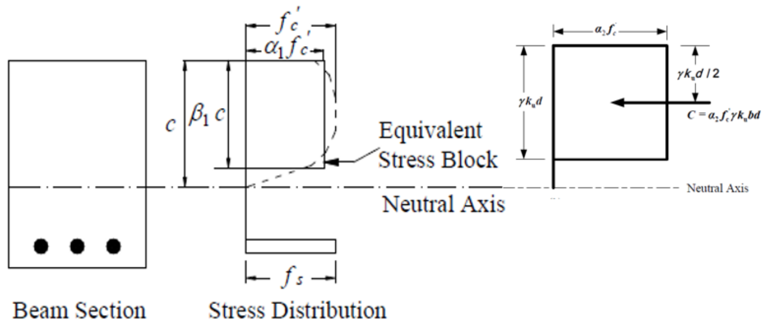

Figure 1. Equivalent Rectangular Stress Block

Building Code	AS3600:2018	ACI318M-14
α_2 (*α_1 for ACI code*)	*0.85-0.0015 f′c ≥ 0.67*	*0.85*
γ (*β1 for ACI code*)	*0.97-0.0025 f′c ≥0.67*	*0.85 (f′c ≤ 28)* *0.85-0.05 (f′c ' - 28) / 7 ≥ 0.65*
ε_{cu} (*Ultimate strain of concrete*)	*0.0030*	*0.0030*

Table 1. Comparison of Equivalent Rectangular Stress Block Factor

Note: f'_c in MPa

Comparing α_2 (Stress factor) and γ (Stress block depth factor) of AS3600: 2018 & ACI318M-14 between the two codes by concrete grade is as follows.

The graphs on the next page compare between the stress block depth factor (γ) and the concrete stress factor (α_2) for AS 3600 and ACI318M.

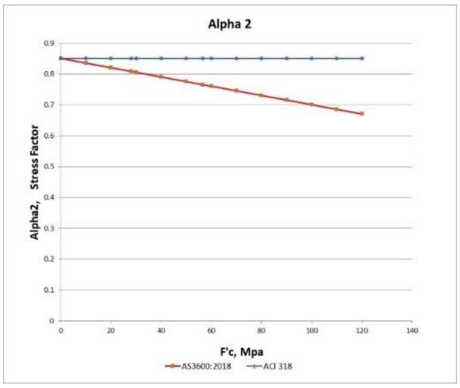

Figure 2a. Concrete Stress Factor (α_2)

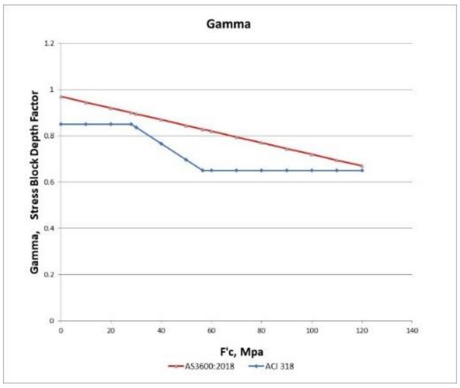

Figure 2b. Stress Block Depth Factor (γ)

The concrete stress factor(α_2) shall be assumed uniformly distributed over an equivalent compression zone bounded by edges of the cross section

The concrete stress factor (α_2) applicable to the rectangular stress block in AS3600:2018 is decreases linearly from 0.85 as the concrete grade increases. In ACI318M, but, the factor remains constant for all concrete grades, 0.85.

The Stress block depth factor (γ_2) for equivalent rectangular concrete stress distribution in AS3600:2018 is decreases linearly from 0.97 as the concrete grade increases. In ACI318M, but, this value is 0.85 for concrete grade below 28 MPa, and 0.65 for concrete grade above 56 MPa. The values in between concrete grades use linear interpolation.

The combined effect of variation in the two factors is shown in the graphs below. The product of γ and α_2 is proportional to the force per unit width, and is referred to below as the Force Factor. The product of the Force Factor and ($1 - \gamma/2$) is proportional to the moment per unit width, and is referred to the Moment Factor.

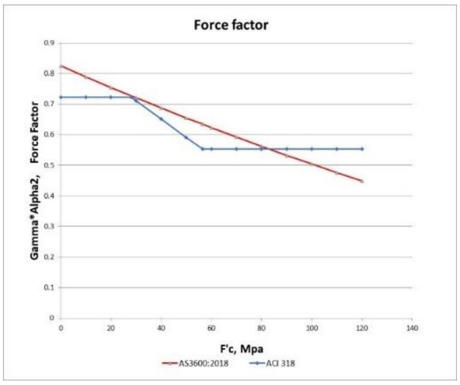

Figure 3a. Force Factor vs Concrete Grade

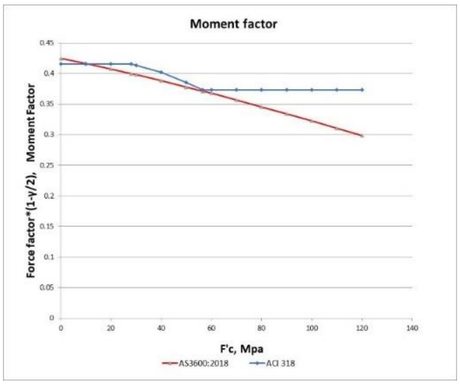

Figure 3b. Moment Factor vs Concrete Grade

It can be seen that the force factor (α_2*γ) value of AS3600:2018 is larger than ACI318M up to 80MPa, but in the case of high strength grades over 80MPa, it is reversed and the ACI318M's value is slightly larger than AS3600:2018's.

For moment factor, except for low-strength grade below 10MPa, the moment factor of ACI318M is larger than AS3600:2018.

1.3. Strength Design in Shear

The shear strength formulas excluding torsional and axial force are compared. In both standards, the shear strength is calculated as the sum of the shear strength of concrete and reinforcement. In the case of general beams with stirrups perpendicular to the longitudinal direction, it can be compared by simplifying the equation below. It was assumed that the general strength reduction factor of the shear was the same (0.75), and the 'effect of the vertical component of prestress' was not considered.

Building Code	AS3600:2018	ACI318M-14
Concrete shear strength, Vc	$\mathrm{V_{uc}} = \mathrm{k_v} b_v d_v \sqrt{f_c'}$	$\mathrm{V_c} = 0.17\lambda\sqrt{f_c'} b_w d$
Reinforcement shear strength, V_s	$\mathrm{V_{uc}} = \left(\frac{A_{sv}\mathrm{f}_{sy.f}\, d_v}{s}\right)\cot(\theta_v)$	$\mathrm{V_s} = \frac{A_v \mathrm{f}_{yt} d}{s}$
Minimum shear reinforcement [$A_{sv.min}$ / s]	$\frac{A_{svmin}}{S} = \frac{0.08\sqrt{f_c'} b_v}{\mathrm{f}_{sy.f}}$	$\mathrm{Max}[0.062\sqrt{f_c'}\left(\frac{b_w}{\mathrm{f}_{yt}}\right), 0.35\left(\frac{b_w}{\mathrm{f}_{yt}}\right)$
Maximum shear strength, [$V_{u.max}$]	$\mathrm{V_{umax}} = 0.55\left[0.9 f_c' b_v d_v \left(\frac{cot\theta_v + cota_v}{1+\cot^2\theta_v}\right)\right]$	$0.83\sqrt{f_c'} b_w d$

Table. Comparison of Shear Strength

1.3.1 Concrete Shear Strength, V_c

In the case of AS3600:2018, the k_v value is changed according to the amount of shear reinforcement placed compared to the minimum shear reinforcement per spacing, $A_{sv,min}/s$. The concrete shear strength calculation is reflected according to the shear. Also, the K_v is calculated using a variable of k_{dg} (nominal aggregate size factor).

This is considered to be a formula that reflects not only the shear stress resisted by the concrete on the compression side without a crack ('shear stress in concrete'), but also the 'interlock action' of the aggregates and the increase in the shear resistance performance due to the 'dowel action' of the longitudinal reinforcement. In the case of ACI318M, it is replaced with a constant value (*0.17λ*) taking this effect into account.

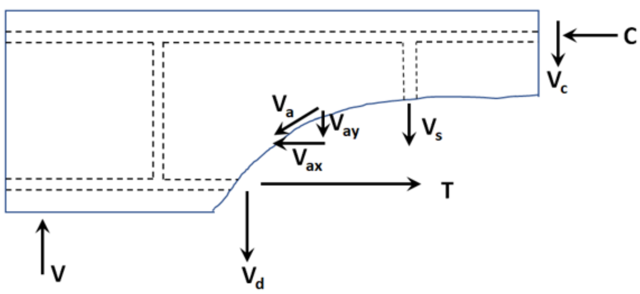

Figure 4. Overview of Shear-Resisting Mechanisms on Crack

※ Note

① V_c: Shear Stress in Concrete

② V_{ay}: Aggregate Interlock Action

③ V_d: Dowel Action

④ V_s: $=nA_vf_v$ Vertical Force by Shear Reinforcement

In 'simplified method' in AS3600:2018, the value of k_v may be determined as follows for normal weight concrete with $f'_c \leq 65MPa$:

(a) $For\ \frac{A_{sv}}{s} < \frac{A_{svmin}}{s}\ then\ k_v = \frac{200}{1000+1.3d_v} \leq 0.15$

(b) $\text{For} \frac{A_{sv}}{s} \geq \frac{A_{svmin}}{s}\ then\ k_v = 0.15$

1.3.2 Reinforcement Shear Strength, V_s

In the case of shear reinforcement in the perpendicular direction, θ_v (angle of inclination of the compressive strut, $\theta_v=29+7000\varepsilon_x$: ε_x is the longitudinal strain in the concrete) may be taken as 36 degree in simplified method of Chapter 8.2.4.3. When this value is applied, cot (36°) is about 1.376, so it is expected to be somewhat larger than the ACI318M value (1.0). In addition, since the definition of effective shear depth is different according to codes, it is expected that the V_s value calculation will be different depending on the variables of θ_v and effective shear depth (d).

1.3.3 Minimum Shear Reinforcement, $A_{sv,min}/s$

For ACI318M, the larger of the two formulas specifies the minimum shear reinforcement, which is the larger value of f'_c starting at about 32MPa. For AS3600:2018, it increases proportionally to the square root of the concrete strength. If the coefficient excluding *B(Section Width)/*f_{ys} *(Reinforcement Strength)* is defined as 'minimum shear reinforcement factor', a comparison graph between the two standards is as follows.

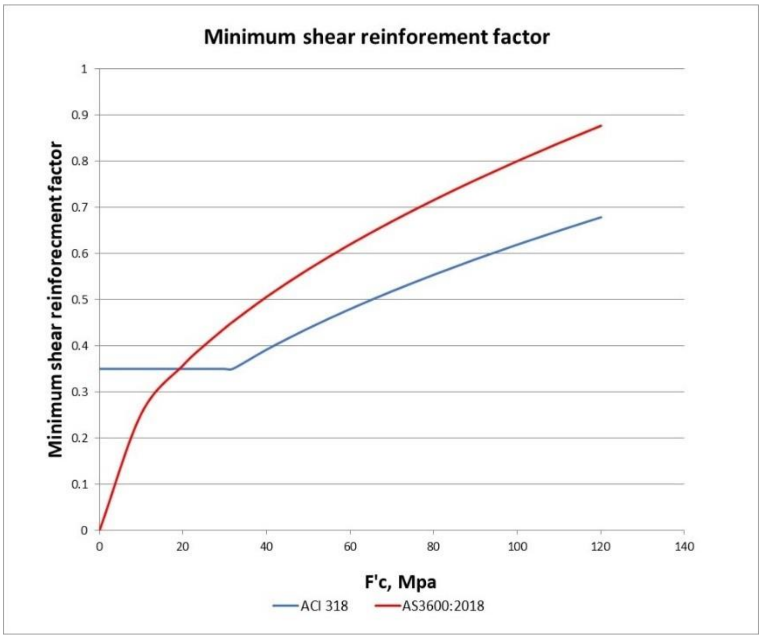

Figure 5. Minimum Shear Reinforcement Factor vs Concrete Grade

As shown in this graph, AS3600:2018 requires a higher amount of shear reinforcement than ACI318M when the concrete compressive strength f'_c is 20MPa or more.

1.3.4 Maximum Shear Strength, [$V_{u.max}$]

In the case of ACI318M, the formula for calculating the maximum shear strength is limited to 5 times or less than V_c *(0.16667(≒0.17) x 5 ≒ 0.83).* Also, the formula that increases in proportion to the square root of concrete strength applied ($\sqrt{f'_c}$). In the case of AS3600:2018, unlike ACI318M, the increase is linearly proportional to the concrete strength (f'_c).

1.4. PM Interaction

The combined effect of these variations for a 500mm by 500mm rectangular column is shown in the interaction diagrams below:

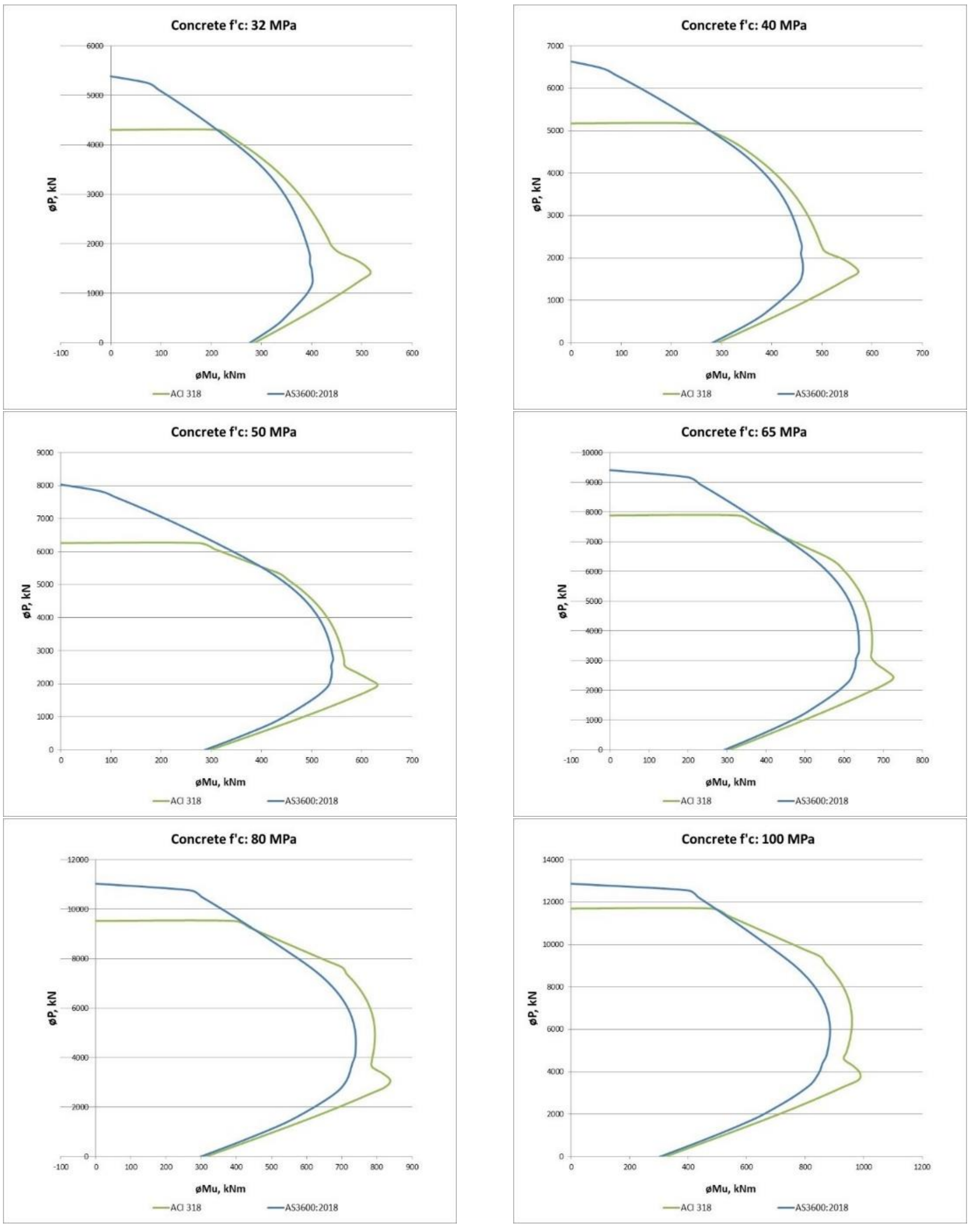

Figure 6. Interaction Diagrams

The comparison is limited to 'short column' ignoring the effect of long columns.

For ultimate design axial strength in compression without bending, in AS3600:2018, the strength reduction factor (ϕ) is 0.65, whereas in ACI318M, the strength reduction factor (ϕ) between ties and spirals differs by 0.65 and 0.75, respectively. This takes into account the increase in ductility due to the confine effect.

Also, in ACI318M to account for accidental eccentricity, the design axial strength of a section is limited to 0.8(ties type) and 0.85(spirals type) of the nominal axial strength. In AS3600:2018, controlled by minimum load eccentricity. It is a little higher than the ACI318M value for strength grades up to 50MPa.

For strength grades above 50MPa, the "compression controlled" strength from ACI318M becomes progressively greater than that found in AS 3600. This difference is due to the constant concrete stress factor (*0.85f'c*) used in ACI318M, compared with a reduction factor for the rectangular stress block in AS3600 (*1.0-0.003f'c*) Therefore, the ACI code appears to be unconservative in this respect.

For the transition area from “tension controlled” to “compression controlled” sections results, for the differences in the method of calculation of the strength reduction factor (ϕ) and α_2 & γ for equivalent stress block factor, AS3600:2018 have significantly more conservative for axial loads approaching the balance load.

For "tension controlled" area, the differences of the strength reduction factor (ϕ), 0.9 for ACI318M, 0.85 for AS3600:2018 have more conservative for moment capacity in same axial loads.

1.5. Development Length

Building Code		AS3600:2018	ACI318M-14
Development of deformed bar in tension	Simple	$L_{sy.tb} = \frac{0.5k_1k_3f_{sy}d_b}{k_2\sqrt{f_c'}} \geq 0.058f_{sy}k_1d_b$	$\frac{f_y\psi_t\psi_e}{k\lambda\sqrt{f_c'}}d_b$ K=2.1,1.7,1.4,1.1
	Detail	$L_{sy.t} = k_4k_5L_{sy.tb}$	$l_d = \left(\frac{f_y}{1.1\lambda\sqrt{f_c'}}\frac{\psi_t\psi_e\psi_s}{\frac{c_b+K_{tr}}{d_b}}\right)d_b$
Development of deformed bars in compression	Simple	$L_{sy.cb} = \frac{0.22f_{sy}}{\sqrt{f_c'}}d_b \geq 0.0435f_{sy}d_b\ or\ 200mm$	(a) $\frac{0.24f_y\psi_r}{\lambda\sqrt{f_c'}}d_b$ (b) $0.043f_y\psi_rd_b$ Max [(a),(b)]
	Detail	$L_{sy.c} = k_6L_{sy.cb}$	
Development of standard hooks in tension		$0.5L_{sy.t}$	(a) $\frac{0.24f_y\psi_e\psi_c\psi_r}{\lambda\sqrt{f_c'}}d_b$ (b) $8d_b$ (c) 150 mm Max [(a),(b),(c)]

The concepts of calculation of development length between two codes are similar.

It is proportional to the diameter and tensile strength (f_y) of the reinforcement. When the reinforcement embedded in the concrete acting on force, development length is the minimum embedding length that allows the maximum stress to be exerted up to the yield strength without deformation such as pulling out or slippage.

Also, it is inversely proportional to the square root of concrete compressive strength ($\sqrt{f'_c}$). The purpose is to allow the reinforcements to yield before ‘breakout failure’ occurs due to the shear stress generated at the interface between the reinforcement and the surrounding concrete.

In the case of the development of deformed bar in tension, both codes are used in ‘simple’ and ‘detail’ formulas.

The ‘simple’ formulas consists of similar concept of parameters, like reinforcement location factor ($k_1 ≒ \psi_t$), size factor ($k_2, k_3 ≒ \psi_s$), epoxy-coating factor ψ_t, lightweight concrete factor ,λ.

In the case of 'detail', both codes included coefficients considering the 'confinement of the transverse reinforcement'. In AS3600:2018, the multiplication of k_3, k_4, k_5 shall be not taken as less than 0.7, and in ACI318M, the confinement term is limited not to exceed 2.5, so that it is limited due to the confinement effect of the transverse reinforcement.

As a result of comparing the two codes for 'Development of deformed bar in tension', in general, the difference between 'Simple' method and 'Detail method' was smaller in AS3600:2018 than in ACI318M-14. In other words, it is understood that the 'simple' calculation result of ACI318M-14 applied more conservative approaches.

Also, in both codes, development length to develop less than the yield strength is possible when the 'tensile stress ($A_{s,required}$)' does not exceed 'yield strength($A_{s, provided}$)', and it is possible to reduce the development length by that ratio.

[Reference]

AS 3600:2018: Concrete structures, Australian Standard

ACI 318M-14: Building Code Requirements for Structural Concrete, American Concrete Institute

https://newtonexcelbach.com/

"shear capacity of steel fibre reinforced concrete beams" by Belkis Filian Abad'

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CONTACT

E.MAIL | midasStructure@midasit.com
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